FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

Multimodal vs. Unimodal Physiological Control in Videogames for Enhanced Realism and Depth

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Mestrado Integrado em Engenharia Informática e Computação

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Abstract

In the last two decades, videogames have evolved in a nearly explosive way, from text-based adventures and pixelated graphics to the near-realistic 3D environments that are common in the super-productions of big game companies (AAA titles). Although this tendency was not mirrored in the games' interaction devices area, recent studies in the Human-Computer Interaction field (HCI) have explored biofeedback interaction as an alternative to the current devices.

In the context of HCI and videogames, this dissertation explores direct biofeedback: the explicit manipulation of physiological data (i.e. one's own body) in order to perform actions inside the game. Usually, prototypes of this biofeedback type bind to each game mechanic a single physiological sensor. Although this integration is easy and quick, we consider that it has the pitfall of being too simple - it does not yet justify changing from the act of pressing a button to run to a physical action such as raising one's foot. As a consequence, this excessive simplicity wastes the vast potential that we believe to exist in this technology, to create games of increasing complexity and higher depth.

To answer to these limitations, in this dissertation we strive down an unexplored path by combining more than one sensor in a single game mechanic, which we call Multimodal Direct Biofeedback. Using the Unreal Development Kit, we created a First-Person Shooter capable of simulating reliably real-life actions, such as attenuating the recoil of a gun and underwater exploration by using the player's breathing data, among other mechanisms. To assess pros and cons of this new biofeedback type, we developed three distinct versions of the game: Vanilla (Keyboard/Mouse, for modern games), Unimodal Biofeedback (Keyboard/Mouse + 1 sensor per each game mechanic) and Multimodal Biofeedback (Keyboard/Mouse + 2 sensors per each game mechanic).

This prototype was tested by 32 participants whom compared the three versions of the game mechanisms (and each version as a whole) in terms of Fun, Ease of Use, Originality, Playability and Favourite Condition along with another questionnaire targeted at other parameters (IMI Questionnaire). Additionally, the participants compared the three versions of the mechanisms by using 12 keywords which are relevant to the game design of the game, and provided a great quantity of feedback and commentaries about the various elements of the three versions.

In compliance with previous studies, both biofeedback versions were considered more fun than the vanilla version. The unimodal and multimodal versions received similar scores in parameters such as "Fun" or "Playability", but both were appreciated by the players: the unimodal version for its simplicity of use, and the multimodal for its realism, activation safety and depth added to the game. Our biggest contribution is that multimodal biofeedback can have a quite relevant impact in terms of added depth, depending on the way it is used inside the game. On a boundary case, it can be used to increase the feeling of empowerment on the player when using certain abilities, or to intentionally make in-game actions more difficult by demanding more physical effort from the player. We believe that both biofeedback types should be combined simultaneously depending on the sensations that game designers wish to convey to the players.

Resumo

Nas duas últimas décadas, a área dos jogos de vídeo evoluiu de uma forma quase explosiva a partir das aventuras em texto e gráficos pixelizados para os ambientes 3D quási-foto-realísticos comuns nas super produções das grandes empresas. Apesar desta tendência não se ter verificado nos dispositivos de interação com os jogos, estudos recentes no campo da Interação Pessoa-Máquina (IPM) têm explorado a interação através de *biofeedback* como uma alternativa aos dispositivos atuais. No contexto da IPM e jogos de vídeo, esta dissertação explora unicamente a vertente do biofeedback direto: a manipulação explícita dos dados fisiológicos (ou seja, o próprio corpo) para realizar ações dentro do jogo. Os protótipos tradicionais deste tipo ligam a cada mecânica de jogo um único sensor fisiológico e embora esta integração seja fácil e rápida, consideramos que peca por ser demasiado simples e ainda não justifica a troca do ato de carregar num botão por uma ação física como levantar um calcanhar para correr. Por sua vez, esta simplicidade excessiva desperdiça o potencial vasto que acreditamos existir nesta tecnologia para criar jogos complexos e de maior profundidade.

Em resposta a estas limitações, nesta dissertação enveredámos por um caminho não explorado ao combinar mais do que um sensor em cada mecânica de jogo, a que chamamos Biofeedback Multimodal Direto. Foi criado no *Unreal Development Kit* um *First-Person Shooter* capaz de simular fiavelmente ações reais como conter o recuo de uma arma, levar a cabo exploração subaquática, entre outros. Para conhecermos os prós e contras deste novo tipo de biofeedback, foram desenvolvidas três versões distintas: Standard (Teclado/Rato, para os jogos atuais), Biofeedback Unimodal (Teclado/Rato + 1 sensor por mecânica de jogo) e Biofeedback Multimodal (Teclado/Rato + 2 sensores por mecânica).

Este protótipo foi testado por 32 voluntários que compararam as três variantes dos mecanismos do jogo (e cada variante na totalidade) em termos de Diversão, Facilidade de Uso, Originalidade, "Jogabilidade", Condição Preferida e utilizando um questionário direcionado a outros parâmetros (IMI Questionnaire). Adicionalmente, avaliaram as três variantes dos mecanismos com recurso a 12 palavras-chave relevantes ao *game design* do jogo e forneceram um vasto leque de comentários sobre os vários elementos das três variantes.

Em concordância com estudos anteriores, ambas as versões de *biofeedback* foram mais divertidas que do a versão standard. As variantes unimodal e multimodal receberam pontuações semelhantes em parâmetros como "Diversão" ou "Jogabilidade", mas ambas foram apreciadas pelos jogadores: a unimodal pela sua simplicidade de uso, e a multimodal pelo seu realismo, segurança de ativação e profundidade acrescentada ao jogo. O nosso maior contributo é que biofeedback multimodal pode ter um impacto bastante relevante em termos de profundidade acrescentada, dependendo do uso que lhe for dado dentro do jogo. Nos casos extremos, pode ainda servir para aumentar a sensação de poder no jogador ou para dificultar intencionalmente uma ação dentro do jogo ao exigir mais esforço físico. Acreditamos que ambos os tipos devem ser combinados em simultâneo em função das sensações que os criadores de videojogos queiram transmitir aos jogadores.

Acknowledgements

Finally, the longest project of my Master's degree is over. I was far from imagining all the hard work that would come with this project, the first time I put my eyes on it. But even after all the tough times and opting to work on it for six extra months, I would still choose to work on this project all over again. More than my contribution to biofeedback research applied to videogames, this work is also dedicated to all the people who make or love videogames. This project wouldn't exist without you!

To my supervisors, Professor Rui Rodrigues and Pedro Nogueira, a huge "thank you" for believing that I was the man for the job, despite my not-so-long experience in games development, and for accepting my suggestions that took this project "to the next level" (in a manner of speaking).

To Chris Holden, for allowing us to use and modify his original "Dungeon Escape" UDK map — a simple thing as a "yes" made all the difference in this project and allowed us to reach the desired graphical quality of the game. A huge thank you!

I feel obliged to give credit to the author of *"Game Design Workshop"* — Tracy Fullerton —, who wrote a wonderful book on Game Design which inspired me over the course of this project. It's in the little details and additional effort of this thesis that this book's magic is present.

Finally, to those dearest to me: to my parents, family and dogs for keeping me healthy and mentally sane during all this time; to my close friends for all the fun times, the *very early* pilot testing and helping me push forward; and a special thanks to my girlfriend, as she put it nicely, "for putting up with me all the time". There is no better researcher than a happy one.

Thank you!

Gonçalo Filipe Silva

"The essence of a game is rooted in its interactive nature,
and there is no game without a player."

Laura Ermi, Frans Mäyrä

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Abbreviations

AI	Artificial Intelligence
DLL	Dynamic Link Library
EDA	Electrodermal Activity
ECG	Electrocardiography
EEG	Electroencelography
EMG	Electromyography
FPS	First-Person Shooter
GAZE	Eye Gaze Tracking Sensor
GLOVE	Hand Tracking Glove Sensor
GSR	Galvanic Skin Resistance
HCI	Human Computer Interaction
HR	Heart Rate Sensor
NUI	Natural User Interface
RESP	Respiration Sensor
SCL	Skin Conductance Level
UDK	Unreal Development Kit

Chapter 1

Introduction

1.1 Context: Evolution of Videogames and Biofeedback

Modern videogames have drastically evolved in the past two decades from simple text-based and pixelated graphics to near-photorealistic worlds featuring massive amounts of available content to explore and interact with. With the introduction of these massive worlds, videogames have evolved into complex experiences riddled with interactive and engaging narratives, realistic gameplay mechanics and intricately designed artificial intelligence (AI) systems, all of which aim to close the gap with real life as much as possible. Ultimately, videogames are played for the exclusive, highly emotional and rewarding experience that they deliver to players [EM07]. At the end of 2013 we entered the eighth generation of videogame platforms with new input devices, but this new generation still adheres primarily to the gamepad-type convention. Computer platforms still adhere to the keyboard/mouse convention, as well.

The keyboard/mouse and gamepad control schemes have been the most popular conventions for videogames and over time these devices have evolved along with the gaming platforms. While the game platforms themselves have evolved in terms of computational and rendering power, the interaction devices have evolved mostly in the direction of usability – either to accommodate different play styles or to become more ergonomic. Heavily marketed towards hard-core gamers, the industry produced keyboards and mice with ergonomic layouts, customizable weight, programmable keys or gamepads in many different shapes and sizes – mostly based on the premise that familiarity with a certain controller guarantees a good performance in the game [Bro07, KT02].

Throughout the years game companies have tried to create new technologies to step away from the traditional devices, with the most recent attempts focusing on natural user interaction (NUI) devices: the Nintendo Wiimote, the Microsoft Kinect and the PlayStation Move. With these new natural interaction devices, players can now hold a hero's sword in an adventure game (*"The Legend of Zelda: Skyward Sword"*, 2011), ride an inflatable boat through a river (*"Kinect Adventures"*, 2010) or move a wizard's wand to cast spells (*"Wonderbook: Book of Spells"*, 2012).

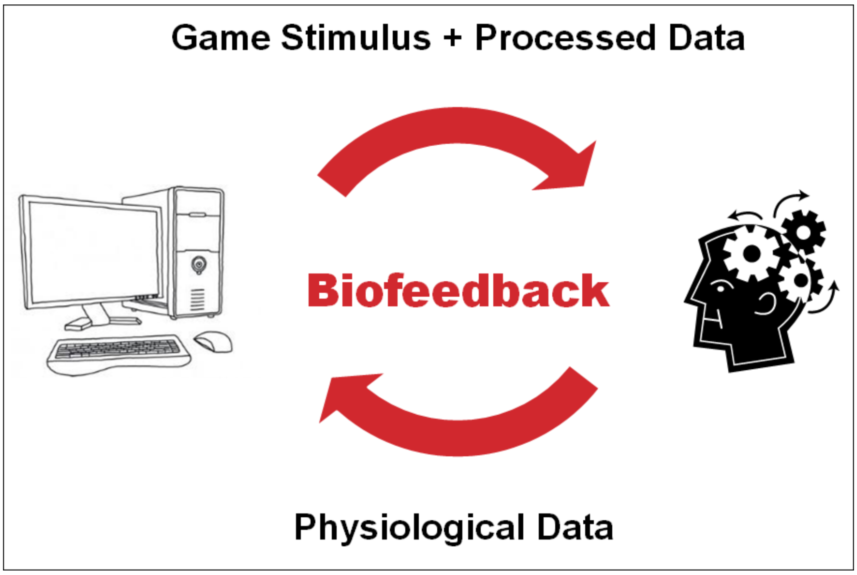

Figure 1.1: Diagram depicting the flow of raw and processed (audiovisual) physiological data between the player and the game.

Recent research in the Human-Computer Interaction (HCI) field has worked on reintroducing the concept of including real-time physiological data from players in real-time applications through the use of **Biofeedback** devices. Biofeedback was created originally in the field of medicine in the 1980s as a training procedure to overcome medical conditions but in the last decade has found its way to two main applications in game HCI research (Figure 1.1). These are Direct and Indirect Biofeedback:

- The player intentionally manipulates physiological data (i.e. their body), which is read by the system in order to perform actions. The player is an active agent in the transfer of physiological data.

- The system reads the player's physiological data and uses it to modify internal aspects or its behaviour, but without him/her being aware of how is physiological data affected the game. The player is a passive agent in the biofeedback process.

The second type is more commonly connected with **Affective Gaming** [GDA05], where the player's emotional state is estimated from the collected physiological data and game parameters are modified in a meaningful way [BBM+07, CPC+09, HB00, MA07, Nog13, NTR13, NRON13a, RSL05, Tor13, YMJ10]. It can still be considered a biofeedback system as it uses Biofeedback instrumentation to read physiological data and present it back to the player, hence closing an interaction loop. This type of biofeedback system is commonly referred to as Affective Biofeedback and is a very promising area of Affective Computing. In this dissertation, however, we will be focusing only on direct biofeedback.

Adapting traditional videogames to make use of direct biofeedback has been tested in the past with promising results. However, these game adaptations have focused mostly on indirect and simple game mechanics [NKLM11, DC07, KLT+10]. Additionally, we believe that until now no biofeedback games have managed to take full advantage of the physiological devices' potential. Regarding the game design aspects, physiological sensors in these games are integrated in a very shallow way and their contribution to gameplay – without accounting for the different sensation of activating an action in-game using our own body – seems uncertain when compared to pressing a button in modern games. In [Amb11], SCL is used in *"Alien Swarm"* simply to define how fast the game timer counts down to zero. In [DC07] and [KLT+10], only indirect biofeedback is explored heavily, with the player "forfeiting game control" (i.e. gameplay freedom) in order to access to abilities such as invisibility, x-ray vision or faster firing rate. Because these mechanics are activated using indirect biofeedback, players do not know when they are going to activate those abilities and thus fail to fully benefit from them. We consider that biofeedback-powered abilities designed in this manner are oversimplified and end up unbalancing the game (i.e. making it too easy), which after a while will result in boredom due to the lack of an appropriate challenge.

Ermi and Mäyra affirm that *"the essence of a game is rooted in their interactive nature"* [EM07]. Since physiological data contains literal information on how we are controlling our own body, we feel there is a great untapped potential in direct biofeedback games. Given this premise, our question is whether introducing more aspects of our physiological behaviour into the game, we can increase this *"essence of interactivity"* expressed by Ermi and Mäyra. In our opinion, by increasing the biofeedback mechanics' complexity we can leverage that potential to create games with far more depth and improved game design.

1.2 Document Structure

Before elaborating further on how we tried to increase this *essence of interactivity*, we take a glimpse at the current state of the art of biofeedback research in two areas: Medicine and Games/Entertainment (Chapter 2). Additionally, we provide a dedicated sub-section to introduce the physiological sensors used in this dissertation with examples of their previous use in research.

In Chapter 3 we approach the requirements for our game and the criteria followed in the creation of the biofeedback game mechanics, before implementing the actual game. In Chapter 4 we present the final game and its biofeedback game mechanics, along with the system's architecture and additional efforts done to refine the quality of our work. In Chapters 5 and 6, we present our empirical study with 32 regular players testing our biofeedback game in three interaction versions (one of them with standard keyboard/mouse interaction, and the other two augmented with biofeedback) and present their analysis of the game according to objective criteria (e.g. rating parameters of Fun on a scale of 0 to 5) and subjective criteria (associating a list of keywords to each game version and open-ended post-game commentaries).

Finally, we reflect on our work by analysing the collected data and the limitations of this study (Chapter 7), presenting future avenues of research in biofeedback (Chapter 8) and the conclusions of this dissertation (Chapter 9).

Chapter 2

Related Work

A review of the current state of the art on biofeedback and its closest related fields is provided in the following sections. Most of the previous work done on physiological interaction has focused on testing how well it applies to medical therapy and in establishing guidelines of use for new fields such as emotional recognition [MA07, LCCS07, HGSW04, NRON13b, NRON13c] and affective digital games [GDA05, YMJ10, KBWA04].

2.1 Field of Medicine

Biofeedback was first commonly used in medical therapy as a training treatment to overcome medical conditions or patient monitoring [MB+91, BEV+96]. In [DLH+10], a mobile platform for music therapy was presented, where users' negative emotional states were counterbalanced through music. In a similar approach, [RBF+08] presented a system for body balance rehabilitation by using simple audio frequencies to indicate correct posture.

Also in the field of rehabilitation treatments, Huang developed an interactive biofeedback system for motor rehabilitation inside a 3D virtual world where patients try to complete tasks while receiving musical and visual feedback in real-time [HIO+05]. Cho, Wang and Mingyu developed EEG-based systems that have the potential to treat medical conditions such as the Attention Deficit Hyperactive Disorder (ADHD) [WSN10, MJNQ06, CLK+02].

Given biofeedback's seemingly easy integration with videogames and high potential in medical treatments, various serious games have been designed for aiding in the treatment of medical conditions, such as: treatment of swallowing dysfunctions using EMG signals, where a patient is a fish trying to swallow smaller fish [SBC+11]; treatment of stuttering or similar speech disorders by reading aloud pieces of text while monitoring the patient's GSR level [LG12]; and General Anxiety Disorder treatment by combining biofeedback with virtual reality systems where certain objects inside the virtual world were modified based on the patient's heart rate signal [RGP+10].

There are also other serious games with a more ludic approach. For example, "Brainball" and a relax-to-win racing game introduce a competitive player-versus-player environment where the most relaxed player wins the game [HB00, BMA+01]. While fun and well accomplished, they represent a paradox in games as in a competitive environment players feel more pressured to win and thus need to fight against their natural instinct – they have to relax in order to gain the advantage, which in turn generates more pressure in itself.

2.2 Games and Entertainment

Dekker and Champion modified a level in the *"Half-Life 2"* game where the Heart Rate and the Skin Conductance Level manipulated: the avatar's movement speed and hearing ability; bullet time mechanics; post-processing effects; dynamic weapon damage based on the sensors' levels; invisibility and the ability to look through walls and buildings [DC07]. While we are not sure if the game mechanics were well balanced as a whole and avoided making the game too easy on the players, it also featured examples of good sensor integration such as dynamic sound effects, reactive enemy spawner AI and the echoing of the player's heartbeat in the game – making the game experience highly tailored and personal for each player.

Kuikkaniemi on the other hand tried to create a more balanced Shooter game in order to study differences between Implicit and Explicit Biofeedback. In-game actions like walking, turning, aiming, gun recoil intensity and firing rate were based on the player's SCL and a RESP sensor [KLT+10].

Rani modified dynamically the difficulty level of a Pong game based on the user's anxiety state, which was estimated by real-time analysis of the captured physiological data [RSL05]. Parnandi developed a car-racing game where factors that influenced the game difficulty such as car speed, road visibility due to fog and steering jitter were modified based on the arousal levels of the player (determined by an EDA sensor) [PSGO13].

Ambinder and Valve have also made some experiments with biofeedback on some of their games [Amb11]. The first one used the player's arousal state via a SCL sensor to modify the AI director of the game *"Left 4 Dead"*, which modified in-game events such as enemy spawns, health and weapon placement, boss appearances, etc. The second experiment was performed on *"Alien Swarm"* and connected the player's arousal state to an in-game timer, where higher arousal levels made the timer tick faster. The last experiment used eye-gaze in the game *"Portal"* by using the mouse to control the player's camera and the eye-tracking for aiming tasks.

Nacke worked on the concept of Direct and Indirect Biofeedback to augment interaction with a game [NKLM11]. The developed prototype was a 2D side-scrolling shooter which used physiological sensors to control the avatar's speed and jump power, the enemies' size, the flamethrower's flame length and the weather conditions which affected the boss of the game. Additionally, the player's GAZE was used to paralyze enemies for a limited amount of time. Torres created a procedurally generated horror game — *"VANISH"* —, which uses indirect biofeedback to influence the game's level layout, item and enemy spawns, enemy AI and player character abilities [Tor13].

The use of GAZE in video games has been previously explored, although not exactly in the scope of biofeedback research as Nacke and Ambinder did. Isokoski and Martin presented a preliminary study with a small prototype to compare the efficiency of eye-trackers versus traditional game controllers – it used two types of aiming simultaneously, one being the typical crosshair controlled by the mouse and the other moved by the eye-gaze of the player [IM06]. Smith and Graham [SG06] tested GAZE in three different game genres:

1. Controlling view orientation in a *"Quake 2"* clone, where looking at an object that was not in the center of the screen would automatically rotate the camera to it.
2. Issuing commands to a virtual avatar in the game *"Neverwinter Nights"* by first looking at the target (a point in space or a treasure chest) and then using the left mouse button.
3. A modified version of the arcade game *"Missile Command"* where the eyes were used to aim towards missiles before pressing the fire button.

Istance tested a modified version of the online multiplayer game *"World of Warcraft"* where all interaction with the game was done only using GAZE dwelling [IHVC09].

Using speech recognition and analysing facial features can be considered a form of Biofeedback – we are still discussing physiological features unique to people, and the player can use that kind of information to consciously manipulate voice and facial expressions. In Emotional Flowers, the user's facial expressions are used to influence the growth of a virtual flower at several times during the day [BBM+07]. Cavazza created an interactive storytelling system to speak with virtual characters using emotional speech recognition capabilities: that is, the user's affect was conveyed by his/her voice and the virtual characters would react differently based on the user's answers [CPC+09]. Depending on the different responses given by the user, the narrative of the story would be directed towards different endings. Kim created a virtual snail that reacts dynamically to the user's emotional state, captured by the user's voice, ECG, SCL, RESP and EMG sensors [KBWA04].

Biofeedback has also been used to modify the behaviour of amusement rides: Marshall built a bucking bronco system where the user's breathing can manipulate directly the movements of the bronco – in a similar way to direct biofeedback; or where the system monitored the breathing information and changed strategies mimicking the behaviour of a human operator – closely related to the indirect biofeedback flavour [MRRE+11]. Breath control provided an interesting balance in terms of semi-voluntary control and game design itself – as in one of the conditions the winning strategy of holding breath had the perk of a bronco with reduced movement, the average person eventually has to resume breathing – thus receiving the penalty of harder bronco movements.

Biofeedback has also been used in an automatic bookmarking system suitable for audio books, which was able to detect when users were interrupted by people or any real world events [PCH+11]. In the context of videogames, this could be used to automatically pause the game when the player is distracted or forced to look away from the screen. Unexpected interruptions sometimes provoke frustration on players.

2.3 Primer of Used Physiological Measures

For a quick synopsis of physiological measures in games, see [Amb11] or [KEC+10].

Electromyography (EMG) measures the electrical activity of muscle tissue. There are records of EMG being used for emotion detection [NPI05] and game profiling [NL08], but recent works have used it as a direct form of input for games [NKLM11]. In our study, we use it on an individual's arms and legs for direct input into the game.

A *Torsion Glove* (GLOVE) is a tracker glove with embedded sensors which can detect the degree to which each of the wearer's fingers are individually bent or straightened, and thus falls under the category of direct input[1]. In our study, we use it as a tool to detect different hand poses. We did not find previous works using a physical glove to track gestures. A similar alternative is to use computer vision techniques to indirectly infer hand gestures [BLL02, CGP07], although they are at a disadvantage as the glove devices can track precise data of the wearer's fingers.

A *Respiration sensor* (RESP) is stretched across an individual's chest and can be used to infer the wearer's chest volume or breathing rate [KLT+10]. Some possible game mechanics that can be derived from this information are modulating a character's stamina exhaustion based on the breathing rate, or using the first derivative to detect "silent breathing" periods in a stealth game to avoid being detected by the enemy. In our study, we use it to infer an individual's chest volume.

A *Temperature sensor* (TEMP) is traditionally used to measure body temperature, but in our study we use it by blowing hot air on it [NKLM11].

[1] While this is not traditionally used in Biofeedback research and is more resembling of Performance Capture Animation techniques, participants in our study seem to have considered it as an attractive device and could be used more often in research.

Chapter 3

Prelude: Requirements and Design Choices

3.1 State of the Art Reflection

Our analysis of the current state of the art on biofeedback games brought us to realise that, on most occasions, a game mechanic was matched to a single physiological sensor. In direct biofeedback mechanics specifically, there were no previous studies examining the combination of two or more sensors to produce a fun game mechanic [NKLM11]. This observation provided a simple but critical aspect where we could contribute to biofeedback research in videogames. To this combination of two or more direct physiological sensors we call **Multimodal Direct Biofeedback**, and **Unimodal Direct Biofeedback** on the case where a single sensor is used. Considering this new type of biofeedback which provided a fresh perspective for game design, and the direct physiological sensors available for use, we strived to design a game focused on a meaningful use of the sensors in the game.

3.2 Designing for Biofeedback Interaction

According to Brown [BC04] and Ermi [EM07], two of the aspects that define the player's Immersion in a videogame are game controls and the cognitive and physical (e.g. hand-eye coordination) challenges that derive from gameplay – in our case, the mastery of the biofeedback controls. Particularly, Brown and Cairns [BC04] state that game controls are one of the first barriers of the "Engagement" stage in Immersion. Thus, we can safely assume that if the controls lack in quality, players will most likely reject them. This was an aspect that we wanted to avoid in the biofeedback variants of our game.

To this end, the results collected by Nacke in his biofeedback 2D platformer provided a good starting point in the design of our prototype:

> *"Participants preferred physiological sensors that were directly controlled because of the visible responsiveness. (...) Physiological controls worked most effectively*

> *and were most enjoyable when they were appropriately mapped to game mechanics. (...) For example, when breathing out triggered a longer flame of the flamethrower, blowing hot air on the temperature sensor decreased the amount of snow, or flexing the leg muscle increased speed and jump height."* [NKLM11]

However, he also mentions the added tension of realistic or natural mappings versus the highly imaginative possible scenarios of videogames [NKLM11]: *"Natural mappings may present more intuitive game interfaces, but also limit the flexibility and generality of the sensors for game control."*

Rather than prioritizing the game development as a standard Mouse/Keyboard game and then trying to retrofit the physiological sensors to its gameplay mechanics, we strived to design the game from the ground up based on the sensors. This was done to improve the overall game design and ultimately make the experience feel more natural – that is, to minimize players' rejection of the sensors for feeling "forced" or "gimmicky", which are recurring complaints on the more widely-commercialized natural user interface (NUI) systems [TNS13, SLR+11]. In compliance with the immersion theories presented above, it is of general consensus among the gamer community that if a game is unplayable due to terrible game logic or bad controls it won't be played – this was an aspect of considerable importance to us.

Based on these results, we opted to use multimodal biofeedback to simulate interaction with natural mappings, but also with a more physical component in the game[1]. A great example of this is the Sprinting mechanism used in Nacke's platformer [NKLM11], that we decided to re-use in our game. At the same time, we maintained the possibility of using these sensors to *simulate* supernatural actions that are typical in videogames or fiction works in movies and books, while keeping them based on physical actions. These, along with Nacke's findings presented above and our intention to make the physiological sensors the "protagonists of the game" (i.e. a central core to gameplay), were the selected design guidelines that went into the creation of the prototype.

This initial analysis led to the planning of an initial set of game mechanics to be developed using multimodal biofeedback. For example, the following mechanisms were on the initial list: attenuating the recoil of a gun through the combined use of arm action and increased chest volume, telekinesis using the GLOVE device and EMG sensors, a stealth mode combining EMG cables on the legs and breathing data, or the power to confuse enemies (this one being a special power). Some of these ideas did not survive the design and implementation phases, as they were hard to implement due to time constraints or depended directly on our choice of game engine. Other concepts, such as the stealth mode or the telekinesis, were adapted into different game mechanics that could be incorporated in the game without spending additional resources. While the evolution of the original game design over time is perfectly common in the development of consumer-level

[1] This is not meant in the way of *fitness games* that have been popularized by the Wii, for example. By physical component, we mean to literally describe a realistic interaction with the game.

videogames, we will not discuss this process in detail as it is not in the scope of this dissertation. The final design of the game (including the biofeedback mechanisms) is presented in Chapter 4.

3.3 Choosing a Game Engine: Time and Resources

Creating a game from scratch is a task that can range from mere months to years of development. Although the biofeedback interaction mechanisms were meant to be created from scratch, creating other assets relevant to the game (e.g. 3D models, audio, level design, etc.) would not be possible as it would require more time and resources that were not in our reach. However, it was still important to provide a game experience similar to the one present in existing consumer-level games.

Choosing the correct engine proved to be a critical aspect to tackle both issues. To cut down the development time, we first narrowed our choices of game engines to the *CryEngine SDK*, *Source SDK* and the *Unreal Development Kit (UDK)*. Besides the fact that they are free for non-commercial uses and are popular choices in the game industry, they ship with a small amount of assets with good quality, ready for use - which provided us the chance to design our own custom level, if necessary. A more thorough investigation of these alternatives led us to choose UDK, due to the following factors:

- The global architecture of the engine and the set of game classes built on top of their scripting system, *UnrealScript*, was easy to understand on a first sight. Most game objects in the engine can be extended through inheritance (like in ordinary object-oriented languages), and new game features can be inserted without breaking the functionality of existing classes.

- It provided ways to establish communication with the physiological devices (which are located outside the game engine) in an almost trivial manner, using a UDK feature called *DLLBind*. As stated in the engine's documentation[2], developers can create a custom dynamic-link library (DLL) written in C++ with exported functions that can be called in *UnrealScript*. This allows us to inject additional features in the game that cannot be delivered by the engine itself, as is the case with our physiological devices.

This paved the way for our prototype, the "GenericShooter 3000", which has the basic premise of delivering to players a First-Person Shooter (built in *UDK*) where they can execute real-life actions in the game using the complexity of multimodal biofeedback. We present in the next section a final version of our prototype, along with how biofeedback interaction was integrated in the game.

[2] UDK's *DLLBind* documentation and examples - http://udn.epicgames.com/Three/DLLBind.html

Chapter 4

Implementation: A Direct Biofeedback Game

To compare how both multimodal and unimodal biofeedback-augmented videogames impact game design and user experience in modern First-Person Shooter videogames, we are interested in answering the following questions:

1. What are the players' responses to physiologically augmented gameplay mechanics in modern First-Person Shooter games?
2. How do Multimodal and Unimodal mechanisms compare to each other in terms of in-game actions, situation context and player experience?
3. Can we enhance game realism and depth using Multimodal and Unimodal Biofeedback? If so, how far?

As a means to answer the previous questions, three identical versions of the game with different interaction methods were developed:

- **Normal (or Vanilla)** — Mouse and keyboard only.
- **Unimodal** — Mouse/Keyboard plus one physiological sensor per augmented gameplay mechanic.
- **Multimodal** — Mouse/Keyboard plus two physiological sensors per augmented gameplay mechanic.

4.1 "GenericShooter 3000" Game Description

In our game the player has three guns at his/her disposal: a Physics Gun to interact with physics-enabled objects and remove obstacles out of the way when necessary; a Link Gun and a Shock Rifle from the *"Unreal Tournament"* games which function similarly to a machine gun and an ordinary rifle, respectively.

Besides basic locomotion, the main character can also perform other typical actions such as: sprint, jump, crouch, put out torches to solve puzzles and interact with buttons/handles on walls and floors. Lastly, there are two special abilities:

1. Possession — The player enters the body of an enemy and controls it in a first-person view. This leaves the main character's body immobile and vulnerable to nearby enemies for the duration of the possession. The player can use the possessed body to activate doors and switches or to fight other enemies – on certain key points, this ability is the only way to progress in the game. The possession technique has no time limit and ends when the possessed body dies (e.g. fights versus other enemies, drowning, suicidal), the player stops the ability or when the main character's body is killed (in this case the player loses the game).
2. Invisibility — The player becomes invisible to all enemies and may freely roam the level. This technique ends whenever the player interrupts it or after its power level (indicated on the lower left corner of the screen) ends.

Enemies run the same AI algorithm in the entire game and have either the Link Gun or the Shock Rifle. There are no boss encounters at this current stage. For our test scenario, the game takes place in a flooded prison where the main character is incarcerated and has to escape. To this end he/she must find three keys to exit the prison, which for our test purposes is the "winning condition" - that is, players have to keep playing until they manage to escape the prison. The level is based on an existing UDK map called "Dungeon Escape"[1], which we modified as necessary to change the level's interaction logic (e.g. behaviour of gates, handles, switches, spawning enemies) and to include an underwater section that did not exist in the original level. Enemies and obstacles were placed to force usage of all the main character's abilities at some point in the level.

4.2 Game Mechanics Subject to Biofeedback Control

There are a total of eight game mechanisms that are activated differently depending on the game version being played.

4.2.1 Gun Recoil Attenuation

Based on popular FPS titles such as *"Counter-Strike"* or *"Call of Duty"*, the Link Gun and the Shock Rifle move the player's view whenever a shot is fired. In the vanilla version, no attenuation

[1] Created by Chris Holden, who gently authorized us to use the map on our project. The original map is available at http://chrisholden.net/07.htm .

Figure 4.1: Invisibility view mode with an enemy in front. Invisibility's post-processing effects occlude the screen borders and change the color scheme.

is available and the recoil values are approximated as faithfully as possible to the average recoil exhibited in existing FPS titles.

The real-world logic behind this mechanism is that when someone fires a gun, contracting the firing arm and sustaining the breathing cycle will result in steadier aim and reduced weapon kickback effects – in reality this does not necessarily apply, but common popular wisdom dictates otherwise and thus makes the mechanism *feel real* in this way.

In the unimodal version, players can significantly attenuate recoil by contracting their right arm (EMG-Arm). In the multimodal version, players must both contract their right arm (EMG-Arm) and increase their chest volume (RESP) to apply the effect to the same intensity. Activating the mechanism only partially (by either contracting their arm or increasing their chest volume) results in a partial reduction effect. Both biofeedback versions have their recoil values slightly increased to force the usage of the physiological sensors while at the same time trying to approximate the behaviour of a real-life gun.

4.2.2 Invisibility

The time Invisibility can remain active is the same for the three versions – a duration bar is displayed on the lower left corner of the screen (Figure 4.1).

As there is no real-world analogue to becoming invisible, we leveraged a common player behaviour in stealth games - becoming tense and having very shallow, slow breathing (perhaps

Figure 4.2: Underwater post-processing effects with blue tinting and distance-based blurring.

in a subconscious attempt at not making noise in-game, although this behaviour of making too much noise or breathing loudly using the sensors was not implemented in the game). However, to balance the game's design we decided to treat it as a special ability (based on popular fiction works such as *"Dragon Ball"*, *"Eragon"* or *"Harry Potter"*) which requires a feeling of empowerment before activating powerful abilities.

In the vanilla version, players press the "Q" key to become invisible. In the unimodal version, players are required to breathe in (RESP) to activate the power, and hold their breath in order to maintain invisibility active. If they breathe out, the power is deactivated. In the multimodal version, players must first make a closed fist pose (GLOVE) - mimicking the magic seal for a spell or to concentrate power - and then breathe in (RESP) to activate the power, subject to the same no breathing constraints as in the unimodal version.

4.2.3 Underwater Breathing

Similarly to what is done in other titles such as the old *"Tomb Raider"* games, the player has limited time to stay underwater and have their oxygen level displayed on the screen (Figure 4.2).

In the vanilla version, oxygen decreases linearly over time without any intervention from the player.

In both biofeedback conditions the real-world analogies are obvious: players are required to physically hold their breath using only the RESP sensor while they are underwater. Trying to breathe in while underwater results on filling the lungs with water and drown instantly as a result.

Figure 4.3: Possession post-process effects include border overlays with red color (meaning "danger", to be associated with enemies). Keybinds are also communicated on the bottom of the screen (on the Vanilla version only!) as a good design practice followed by videogames.

While this is not what would normally happen in real-life - that is, people would fill their lungs with water and feel a strong need to come to the surface –, earlier playtesting showed that players continued diving ignoring health losses in the character. Ignoring the RESP sensor and health losses was a behaviour that we did not desire in the game, thus we took a more punitive approach to this mechanism.

RESP levels while diving are also connected to the on-screen oxygen bar (Figure 4.2), replacing the vanilla version's decreasing oxygen behaviour.

4.2.4 Possession

In the vanilla version, players take over the enemy's body by pressing the "V" key (Figure 4.3). Similar to other popular titles (in this case *"Dishonored"*), to return to their original body, they can perform a Release action using the "V" key, or a Suicide action using the "H" key.

In the unimodal version, players Possess enemies by blowing hot air on the TEMP sensor, which mimics the player's soul leaving the body as it enters the possession's target. In the multimodal version, players first perform the hand pose displayed (Figure 4.4 on the left) and then blow hot air onto the TEMP sensor. To maintain consistency with the Invisibility technique, this pose resembles the magic seal for a magical ability.

Figure 4.4: Possession hand gestures for both biofeedback versions: initiate and reverse (left), suicide (right).

For both versions, to return to the original body they have to perform one of the hand poses (reverse or suicide) displayed on Figure 4.4.

4.2.5 Fire Blow: Interaction with Fire Objects

This action was designed to be used as a puzzle solving ability inside the game involving torches or other fire objects. In future work we would like for it to also be a stealth mechanic, where blown-out torches decrease the visibility of an AI enemy - it allows for more strategic thinking from the player.

In the vanilla version, players put out a torch or light up a fireplace by pressing the “B” button (Figure 4.5). In the unimodal version, players blow on the TEMP sensor.

In the multimodal version players must first inhale heavily to increase their chest volume through the RESP sensor and finish the action by blowing on the TEMP sensor. Since the in-game puzzles were in the size of torches or fireplaces, they required a larger breathing effort – the multimodal version portrays this interaction more realistically.

4.2.6 Sprinting

On the lower corner of the screen is a stamina bar that shows for how much longer the player can run before being forced to recover his strength (Figure 4.6). Stamina decrease over time and maximum speed are the same on the three conditions.

In the vanilla version, Sprinting is activated by holding down the “Left Shift” key. In the unimodal version, players can lift the left leg’s heel or foot tip (EMG-Leg). In the multimodal version, players are required to use both feet (2x EMG-Leg).

4.2.7 Item Use: Using Objects or Equipping Them

This ability is used to pick up objects inside the game, to open locked doors or to interact with other “usable” game objects. In the vanilla version, players use the “E” key.

Figure 4.5: A puzzle where the player has to light up the fireplace combining a torch and “Fire Blow” to feed power to a non-working gate.

Figure 4.6: The Stamina bar shows on the screen when the player presses Shift or the EMG-Leg sensors are used. A blur effect is applied to the screen to enhance the sensation of running – this is a feature that already exists in the UDK engine which we left unchanged.

Figure 4.7: “Item Use” works on handles to open certain doors, other interactive objects or to equip key items like the Prison Keys (which are required to finish the level).

In the unimodal version, players close the hand equipped with the GLOVE device (Figure 4.7). In the multimodal version, players are required to contract the right arm (or alternatively to move it in any direction) while grabbing the same object with the GLOVE.

4.2.8 Grabbing Objects (Physics Gun)

To use this action players have to equip the Physics Gun. In the vanilla version, this is activated by dragging the Left Mouse Button. In the unimodal version, players close their hand (GLOVE) to grab the object and open it to release the object - to move it while grabbing from one place to another the player can use the WASD keys to move or use the mouse to rotate the camera.

Unfortunately, the GLOVE device did not have an accelerometer and this was an ability that we wanted to perform purely on the GLOVE – players who wished to rotate the camera were forced to do so by moving the mouse with the tip of their closed hand. This is a usability aspect that we wish to improve in future work.

In the multimodal version, players first contract the right arm (EMG-Arm) as in the “Item Use” ability until the “Grab” word on the screen (Figure 4.8) is lit green, and then close their hand (GLOVE) to grab the object - at this stage the arm can be relaxed as the object is being held successfully.

Figure 4.8: A physics-enabled object is covering a hole where the player has to pass through by clearing the way with the Physics Gun.

4.3 System Architecture

To create additional functionality, UDK has the ability to integrate custom developed Windows Dynamic-link Libraries (DLLs) with functions that can be called from inside the UDK's scripting language (UnrealScript). We wrote a custom DLL in C++ which is responsible for retrieving physiological data from outside UDK, resulting in the overall system architecture depicted on Figure 4.9.

The *NeXus-10* device is responsible for capturing physiological data for the EMG, RESP and TEMP signals. Signal processing here is handled by the *Biotrace+* software suit, which also performs the signal acquisition from the NeXus-10 device via Bluetooth. The GLOVE's data stream is accessed by a C++ library provided by the glove's manufacturer.

The *BiofeedbackDLL* provides normalized data into the the game after it is processed by the *Biotrace+* Software suite, as we describe now in more detail.

4.4 Calibration of Physiological Devices

Towards the end of development we quickly felt the need to normalize the physiological devices' data feed to the game – this provided an easy abstraction to work over as we were not working on each person's unique physiological values any more, but rather on the expected behaviour of each of the physiological devices across a general population. For this purpose, we created a very simple

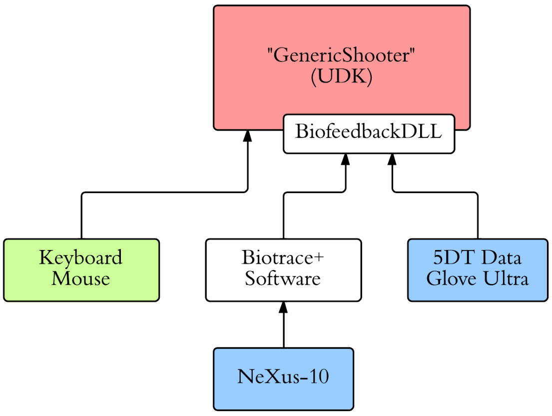

Figure 4.9: System architecture in the biofeedback versions of the game. Players see the result of their actions in the UDK engine.

calibration application in *WinForms* in which we established the maximum and minimum values for each physiological sensor (Figure 4.10). With the exception of the TEMP sensor, all sensors were calibrated for each person before a playtesting session. EMG-Legs, EMG-Arm and RESP were normalized to the [0.0, 1.0] range. The TEMP signal passed to the game only has two states: on and off, represented by a byte of value 0 or 255, respectively. Unlike the other sensors, this one is dynamically post-processed inside the *BiofeedbackDLL* to achieve the toggle-like behaviour.

The raw TEMP data indicates the actual temperature of whatever object the sensor is touching: since in our interaction model it is attached to a headset (in the place of a microphone), the sensor registers room temperature values. To detect when the player is blowing hot air on the sensor (i.e. a temperature difference), we compute an approximation of the TEMP's first derivative by using the current and previous readings of the raw TEMP sensor, divided by the time difference between different game frames ("delta time" in the game). When this instant derivative crosses certain threshold values, determined by trial-and-error, we change the button state of the TEMP sensor.

For the GLOVE device we used automatic calibration and gesture detection capabilities existing in the manufacturer's library – a total of 15 hand poses can be detected by the device.

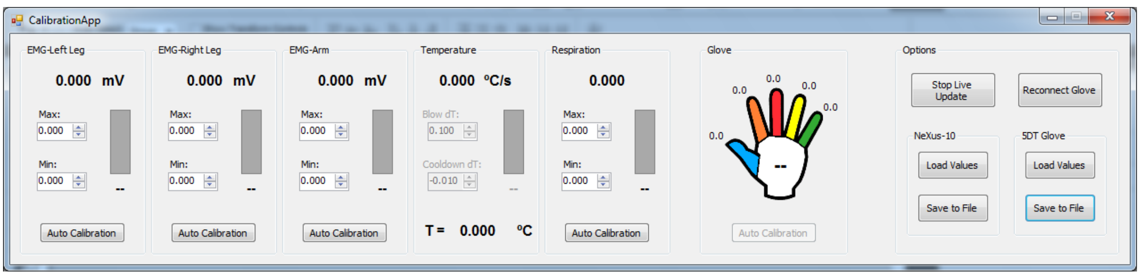

Figure 4.10: Snapshot of the application for calibration of physiological data that we developed. It was also used as a monitoring application to ensure that physiological data was being transmitted correctly to the game.

Figure 4.11: Example of a beta-tester of *"GenericShooter 3000"* with the physiological devices equipped. In this image the following sensors are visible: EMG-Arm, 2x EMG-Leg (top-left corner), RESP and GLOVE. The TEMP sensor was attached to the tip of a headset equipped by the players.

Figure 4.11 shows how the equipment was connected to players.

4.5 Iterative Playtesting and Game Tutorial

To assure the game was played as our game designer intended and had the intended quality in gameplay comparison with existing FPS titles, 8 voluntaries were called for individual pilot playtesting sessions over the course of development as suggested in [Ful08]. This was useful to eliminate small bugs, but also to fine-tune gameplay details and level design issues in all three versions of the game.

Early testing also showed that despite FPS games being a popular genre, some of our game testers always died at the beginning of the prison level. To eliminate this issue – partly inspired by the strong tutorial present in the game *"Age of Empires 2: Age of Kings"* and a testimony from a researcher working in that same game [Ful08, chap. 9, p. 267] – we created a 5-minute playable tutorial level for the three versions where players could fully understand the game and what their character is able to do. Hint boxes inspired by the game *"Antichamber"* (Figure 4.12) were placed in key points of the tutorial level[2] (Figure 4.13) to help the players to activate all mechanisms on their own. From their improved results (none struggled further with the game mechanics) this proved to be a very effective way to introduce both the game on its entirety and how the biofeedback sensors worked as well.

After our *"GenericShooter 3000"* game was finished and was sufficiently refined, we proceeded to conduct our empirical study. To recall our research questions, we are interested in accessing:

[2]Floor and mosaic wall textures created by Hugues Muller - available at http://nobiax.deviantart.com/gallery/#Packs.

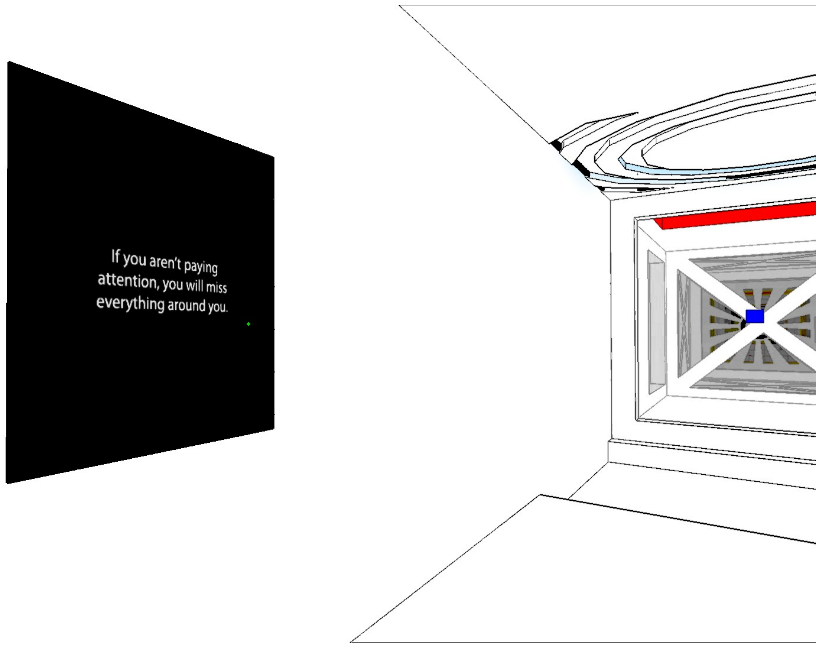

Figure 4.12: Example of a hint message from the game *"Antichamber"*. The message reads *"If you aren't paying attention, you will miss everything around you."*, which alerts the player to be on the lookout for hidden rooms or secret passages nearby.

Figure 4.13: Examples of hint boxes in the Tutorial level. Vanilla versions (bottom), Multimodal Possess (top-left) and Biofeedback Underwater Breathing (top-right).

1. The players' reactions to physiologically augmented gameplay mechanisms in modern FPS shooters;

2. A comparison between multimodal and unimodal mechanisms in terms of in-game action performance, situation context and player experience;

3. Whether we can enhance game realism and depth using multimodal and unimodal biofeedback.

Chapter 5

An Empirical Study with Players

5.1 Game Conditions

The study was comprised of three conditions (**Vanilla**, **Unimodal** and **Multimodal**) represented by the three game versions described in the previous section. Only the latter two used physiological input. Table 5.1 synthesizes the mapping of sensors for each of the eight biofeedback-augmented gameplay mechanics.

5.2 Experimental Protocol

For the study, a three-condition repeated-measures within-subjects design was used. To mitigate order bias effects, each participant played the three conditions on a random order. Test sessions were split in two consecutive parts: Tutorial and Prison Level. Upon arrival, participants were acknowledged for their time and asked to sign a consent form. Afterwards, they were equipped with the physiological devices with a simultaneous briefing on what each sensor was meant to do. The physiological devices were calibrated once before the Tutorial section and recalibrated if necessary at the start of the Prison Level section.

In the first test round, participants played the Tutorial level three times (one for each test condition). By doing so they were able to become accustomed to the game and also to experiment with the different mechanisms from Table 5.1 as they saw fit. At the end of the third Tutorial, players filled a questionnaire where they were asked to compare all mechanisms between the three conditions according to ratings of Fun, Ease of Use and Originality. This allowed us to get valuable insights on which mechanisms had a higher potential to add depth to the game experience (Fun), which were causing issues or improving gameplay (Ease of Use) and which had a highest impact in the overall gameplay. It also became an important step in evaluating our game design choices in the mechanisms themselves.

In a similar way to the word list prompt presented in [GCC+10], we also asked players to compare each mechanism between the three conditions using the list of keywords displayed on Table 5.2. However, we designed ours with a moderate number of keywords to broadly and swiftly

Table 5.1: Mapping of Sensors to Game Mechanics

Mechanism	Unimodal	Multimodal
Gun Recoil	EMG-Arm	EMG-Arm + RESP
Invisibility	RESP	GLOVE + RESP
Underwater	— RESP - same in both versions —	
Possession	TEMP	GLOVE + TEMP
Fire Blow	TEMP	RESP + TEMP
Sprinting	EMG-Leg	2x EMG-Leg
Item Use	GLOVE	EMG-Arm + GLOVE
Grab Object	GLOVE	EMG-Arm + GLOVE

capture differences in positive and negative aspects of gameplay – allowing us to gain a significant insight on their game experience with and without the physiological devices.

In the second test round, participants played the Prison Level three times for each condition until they managed to escape the prison (approximately 15-20 minutes in the initial playthroughs and 5-15 minutes on subsequent runs). At the end of the third Prison Level, players compared each version of the game (Vanilla vs Unimodal vs Multimodal) according to ratings of Originality, Preference and Playability. Playability was inspired in Brown's immersion theory where game controls were an element of the first barrier to immersion, "Accessibility" [BC04]. Being a rather ambiguous term, in the context of our study we presented it to our participants as *"the degree to which they felt the game controls were an obstacle in each condition"* (in simpler terms, the quality of game controls). They were also required to comment their rating choices to justify their opinion and avoid randomly-filled questions.

Lastly, they filled an Intrinsic Motivation Inventory (IMI) Post Experience Questionnaire with each question repeated three times to compare the game versions. Players were ultimately acknowledged again for their participation and received a chocolate bar as a reward.

5.3 Testing Apparatus

The game was played on a 64-bit desktop computer at a 1680x1050 resolution, running Windows 7 Enterprise SP 1 with the following hardware specifications:

- Intel® Core™2 Quad Q9550 @ 2.83 GHz
- 4 GB RAM
- NVIDIA® GeForce® 9800 GTX
- Monitor ASUS VW222S with a size of 22 inches
- 2 desktop speakers of small size

Physiological data was captured using the NeXus-10 device and the 5DT Glove, and integrated in the game using our custom DLL as described in the previous section. The machine's frame

Table 5.2: Card Sorting - Describing Game Mechanics in Words

Useless in-game	Simple	Realistic	Exhausting
Complete ("don't mess with it")	Imaginary	Core in-game	Complex
Confusing	Relaxing	Intuitive	Incomplete ("something's missing")

rates were logged for all three conditions to monitor performance issues that might detract player experience. Luckily, no significant (>5 frames per second) frame rate differences were observed.

5.4 Participants' Demographic Data

Thirty-two participants (29 male, 3 female) aged from 18 to 27 (M=21.28, SD=2.56) participated in the study – before participating in the study sessions they were required to fill a demographics questionnaire. Figure 5.1 depicts the average number of hours per week our participants spent playing videogames.

Players have also reported which game genres they usually play (Figure 5.2) - FPS, Adventure and Action genres were consistently mentioned among players, so we can assume our players to be fairly familiar (even if no proficient) with the genre.

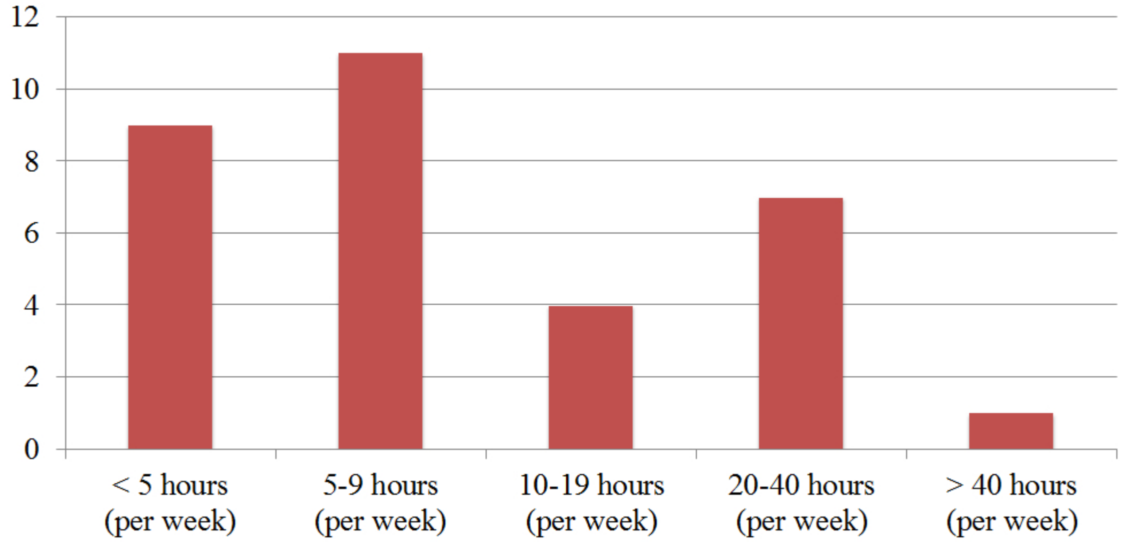

Figure 5.1: The participants’ average time spent playing videogames.

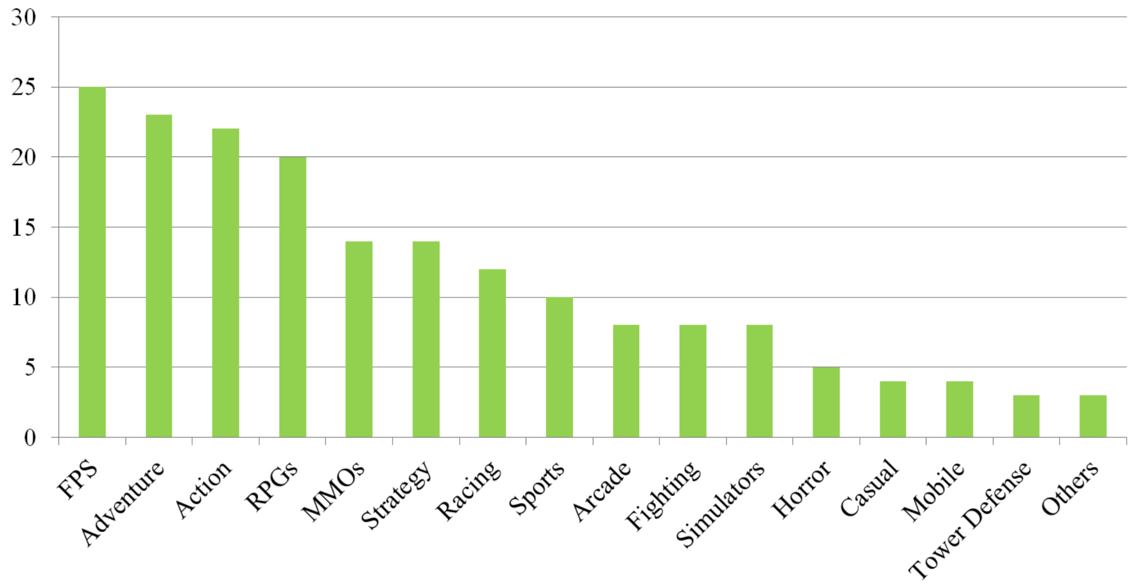

Figure 5.2: Game genres usually played by our participants.

Chapter 6

Empiric Study Results

This section is divided in two main sub-sections. The first of these analyses how participants rated each of the individual gameplay mechanics and how they differed between their variants. Ratings regarding the Fun, Ease of Use and Originality aspects were processed using One-way Analysis of Variance (ANOVA) tests with the Vanilla, Unimodal and Multimodal versions of the game as the within-subjects factor. Post-hoc Tukey tests were performed when statistical significance was met.

For the list of evaluation keywords describing the gameplay mechanics, we present a comparison of the most frequent keywords between the different mechanisms. This is meant as a more subjective and preliminary insight on our participants' game experience.

In sub-section 6.3 we focus our analysis on how participants perceived the overall gameplay experience to be affected across the three gameplay conditions in respect to the components of Originality, Preference and Playability. Finally, for a more objective analysis of player experience provided by each of the game conditions, we resorted to the Intrinsic Motivation Inventory (IMI) questionnaire. Here, the measured components were: Interest/Enjoyment, Perceived Competence, Effort/Importance, Pressure/Tension, Perceived Choice, Value/Usefulness and Relatedness.

6.1 Questionnaire 1: Individual Mechanics

6.1.1 Fun Ratings

In the first questionnaire we asked players to rate the Fun of each mechanism (Figure 6.1) on a scale of 0 (Not fun) to 5(Very fun). For the mechanisms Gun Recoil ($\chi^2(2) = 0.856, p > 0.01$); Invisibility ($\chi^2(2) = 0.805, p > 0.01$); Underwater (it only has two versions, by definition it does not violate the sphericity assumption); Fire Blow ($\chi^2(2) = 0.950, p > 0.01$); Item Use ($\chi^2(2) = 0.996, p > 0.01$) and Grab ($\chi^2(2) = 0.756, p > 0.01$), Mauchly's sphericity assumption had been met. For Possess ($\chi^2(2) = 0.883, p < 0.01$) and Sprint ($\chi^2(2) = 0.644, p < 0.01$) it was violated.

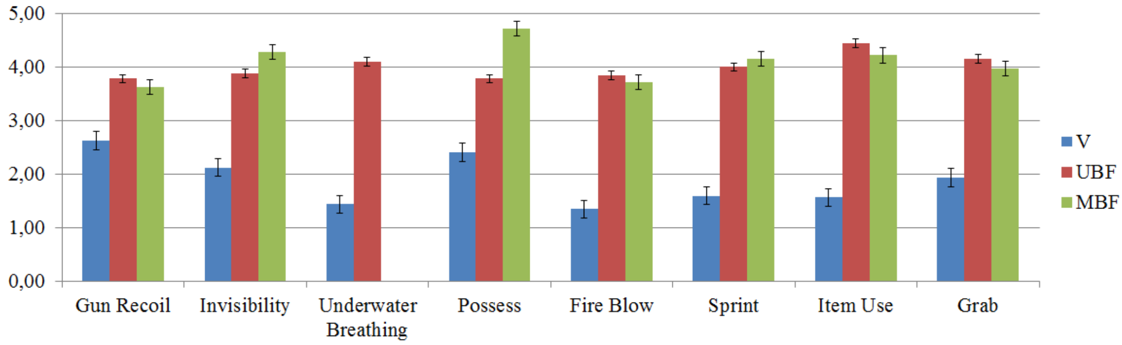

Figure 6.1: Mean Fun values between conditions with corresponding Standard Error measures.

As a result, degrees of freedom for both mechanisms were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.71562$ and $\varepsilon = 0.73746$, respectively).

Statistical significance was achieved for all mechanisms: Gun Recoil $F(2,62) = 13.584, p < 0.01$; Invisibility $F(2,62) = 61.076, p < 0.01$; Underwater $F(1,31) = 114.33, p < 0.01$; Possession $F(2,62) = 64.807, p < 0.01$; Fire Blow $F(2,62) = 77.196, p < 0.01$; Sprint $F(2,62) = 74.975, p < 0.01$; Item Use $F(2,62) = 96.38, p < 0.01$; Grab $F(2,62) = 56.564, p < 0.01$.

Tukey post-huc tests revealed that participants found both the unimodal and multimodal biofeedback versions of the eight mechanics were more fun than the vanilla version of the game ($p < 0.01$). Possession's multimodal version was the only mechanism that players considered more fun than the unimodal version ($p < 0.01$). No further differences were detected in the remaining mechanisms ($p > 0.01$).

The Underwater mechanism did not require a Tukey test nor a Mauchly's sphericity test as it only existed in two versions: vanilla and biofeedback control. It was considered more Fun in the biofeedback control version than the vanilla version.

6.1.2 Ease of Use Ratings

Participants were asked to rate each mechanism also regarding their Ease of Use (Figure 6.2) from 0 (Very hard) to 5 (Very easy). For all eight mechanisms Mauchly's sphericity assumption was met: Gun Recoil ($\chi^2(2) = 0.955, p > 0.01$); Invisibility ($\chi^2(2) = 0.870, p > 0.01$); Underwater; Possess ($\chi 2(2) = 0.883, p > 0.01$); Fire Blow ($\chi^2(2) = 0.830, p > 0.01$); Sprint ($\chi^2(2) = 0.994, p > 0.01$); Item Use ($\chi^2(2) = 0.814, p > 0.01$) and Grab ($\chi^2(2) = 0.874, p > 0.01$).

Statistical significance was achieved as well for all eight mechanisms: Gun Recoil $F(2,62) = 7.281, p < 0.01$; Invisibility $F(2,62) = 24.363, p < 0.01$; Underwater $F(1,31) = 32.137, p < 0.01$; Possess $F(2,62) = 28.981, p < 0.01$; Fire Blow $F(2,62) = 28.257, p < 0.01$; Sprint $F(2,62) = 20.851, p < 0.01$; Item Use $F(2,62) = 40.374, p < 0.01$; Grab $F(2,62) = 46.669, p < 0.01$.

Tukey post-hoc tests showed that players:

1. Found the vanilla versions easier to use than the unimodal versions for Invisibility, Possess, Sprint and Grab ($p < 0.01$);

Table 6.1: Q1 Fun - Statistical Analysis

	One-Way ANOVA		Tukey Post-Hoc		
Fun	F	p	V-UBF	V-MBF	UBF-MBF
Gun Recoil	13.584	< 0.001	< 0.001	< 0.001	0.794
Invisibility	61.076	< 0.001	< 0.001	< 0.001	0.131
Underwater Breathing	111.330	< 0.001		—	
Possession	64.807	< 0.001	< 0.001	< 0.001	< 0.001
Fire Blow	77.196	< 0.001	< 0.001	< 0.001	0.846
Sprint	74.975	< 0.001	< 0.001	< 0.001	0.784
Item Use	96.380	< 0.001	< 0.001	< 0.001	0.612
Grab	56.564	< 0.001	< 0.001	< 0.001	0.698

2. Found all mechanisms easier to use in the vanilla version than the multimodal version ($p < 0.01$)

3. Found Fire Blow, Use and Grab easier to use in the unimodal version than the multimodal version ($p < 0.01$).

No differences were detected for the remaining combinations ($p > 0.01$).

The Underwater Breathing mechanic did not require a Tukey test nor a Mauchly's sphericity test as it only existed in two versions: vanilla and biofeedback control. It was considered easier to use in the vanilla version than the biofeedback version.

6.1.3 Originality Ratings

Originality was rated on a scale of 0 (No originality) to 5 (Very original) – the results are summarized on Figure 6.3. For the mechanisms Invisibility ($\chi^2(2) = 0.746, p > 0.01$) and Underwater Mauchly's sphericity assumption was met. For Gun Recoil ($\chi^2(2) = 0.724, p < 0.01$); Possess ($\chi^2(2) = 0.471, p < 0.01$); Fire Blow ($\chi^2(2) = 0.414, p < 0.01$); Sprint ($\chi^2(2) = 0.473, p < 0.01$); Item Use ($\chi^2(2) = 0.636, p < 0.01$) and Grab ($\chi^2(2) = 0.504, p < 0.01$) it was violated. Greenhouse-Geisser corrections were applied in those cases ($\varepsilon = 0.78344$; 0.65385; 0.63047; 0.65496; 0.73294 and 0.66852, respectively).

Statistical significance was achieved for all eight mechanisms: Gun Recoil $F(2,62) = 203.19, p < 0.01$; Invisibility $F(2,62) = 183.73, p < 0.01$; Underwater $F(1,31) = 317.05, p < 0.01$; Possess $F(2,62) = 127.76, p < 0.01$; Fire Blow $F(2,62) = 154.90, p < 0.01$; Sprint $F(2,62) = 236.54, p < 0.01$; Item Use $F(2,62) = 339.10, p < 0.01$; Grab $F(2,62) = 160.68, p < 0.01$.

Tukey post-hoc tests revealed that players found both biofeedback versions more original than the vanilla version ($p < 0.01$). No differences were detected between the unimodal and multimodal versions ($p > 0.01$).

The Underwater Breathing mechanic did not require a Tukey test nor a Mauchly's sphericity test as it only existed in two versions: vanilla and biofeedback control. Players found that the Underwater biofeedback mechanic was clearly more original than its vanilla counterpart.

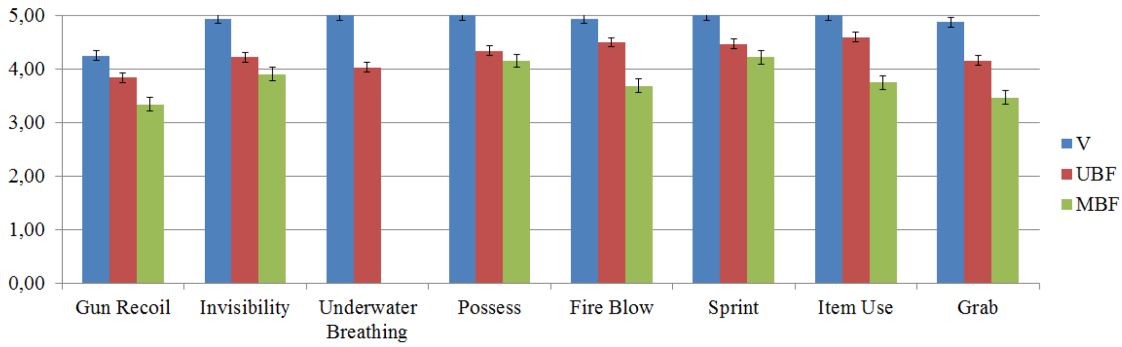

Figure 6.2: Mean Ease of Use values between conditions with corresponding Standard Error measures.

6.2 Gameplay Keywords

Tables 6.4- 6.5 show the results of the participants' evaluation of each game mechanic (in each version) using the presented list of keywords. We will be discussing only relevant results of the table as the amount of information is too extensive for a complete discussion. However, the results are presented as a whole so they can be used as a reference and comparison basis for future work on new direct biofeedback games and game design experiments. To view the gathered data in a more friendly format (column charts), please refer to Appendix A.

The Fire Blow mechanic registered moderate "Useless" values most likely because it was only used as a puzzle-solving ability and did not have much influence in the main action sections of the game. However, we are certain that its evolution to a stealth-related mechanic in the game (see Section 4.2.5) would drop this value to 0% as it would be more relevant to the game.

The "Core in-game" keyword registered an increasing trend in the biofeedback versions, although not on a very significant scale – surprisingly, the multimodal version of Sprint received this adjective 44% of the times (against 28% in the vanilla version). This provides a hint that this mechanic feels more like a core aspect of gameplay on the multimodal version of the game.

For the "Simple/Complex" pair – and within our expectations – the biofeedback conditions suffered relevant decreases towards the vanilla version (especially in the multimodal version) and increases in complexity towards the multimodal version. However, "Complex" did not always translate to something necessarily bad according to players' feedback:

- *"The biofeedback sections don't make the game hard at all, but they make it less fluid compared to the vanilla condition. While on the latter you can walk and open doors quite fast, on the biofeedback versions you have to stop and use the glove"* (P20)
- *"it's complex in a good way, it has depth"* (P15 on multimodal's Gun Recoil)
- *"I liked the unimodal version because we have to use more elements of our body to get immersed in the game itself and it makes it more interesting. The multimodal version is one*

Table 6.2: Q1 Ease of Use - Statistical Analysis

	One-Way ANOVA		Tukey Post-Hoc		
Ease of Use	*F*	*p*	V-UBF	V-MBF	UBF-MBF
Gun Recoil	7.281	< 0.01	0.210	< 0.001	0.098
Invisibility	24.363	< 0.001	< 0.001	< 0.001	0.106
Underwater Breathing	32.137	< 0.001		—	
Possession	28.981	< 0.001	< 0.001	< 0.001	0.249
Fire Blow	28.257	< 0.001	0.031	< 0.001	< 0.001
Sprint	20.851	< 0.001	< 0.001	< 0.001	0.115
Item Use	40.374	< 0.001	0.156	< 0.001	< 0.001
Grab	46.669	< 0.001	< 0.001	< 0.001	< 0.001

step further compared to the unimodal version because it brings a little more complexity (depth) to the gestures execution" (P25)

- *"It's positive because it gives more depth to the game (and more immersion), but other people might prefer something more simple"* (P4 on multimodal's Gun Recoil)

In terms of Realism, both biofeedback versions had the expected results and registered large increases towards the vanilla version. During development phase, underwater breathing was one of the most challenging actions in the biofeedback-controlled versions and we were very curious about the players' reaction to it in the final version:

- *"I wish the diving section was bigger, it was very short."* (P4)
- *"Sometimes I think it would be nice to feel in a movie or game how would it be without breathing"* (P15)
- *"The diving system is very creative and the hand seals system [of the multimodal version] is as well"* (P2)
- *"On the breathing section it was very exhausting – if it were a game with very strong underwater components or we had to repeat it several times it would be very exhausting."* (P16)
- *"I liked all mechanisms in general except for the underwater breathing one."* (P30)

Regarding the "Imaginary" keyword, it was a sibling concept for Realism where a game mechanic could fail to achieve realistic action (because it does not exist in real-life) but was able to reproduce quite well how players would go about performing actions that they could imagine themselves doing (e.g. casting a spell or becoming invisible). This explains why the special abilities Invisibility and Possess obtained the highest results in the "Imaginary" parameter – players seem to identify more with those actions as the they try to tap in the players' imagination.

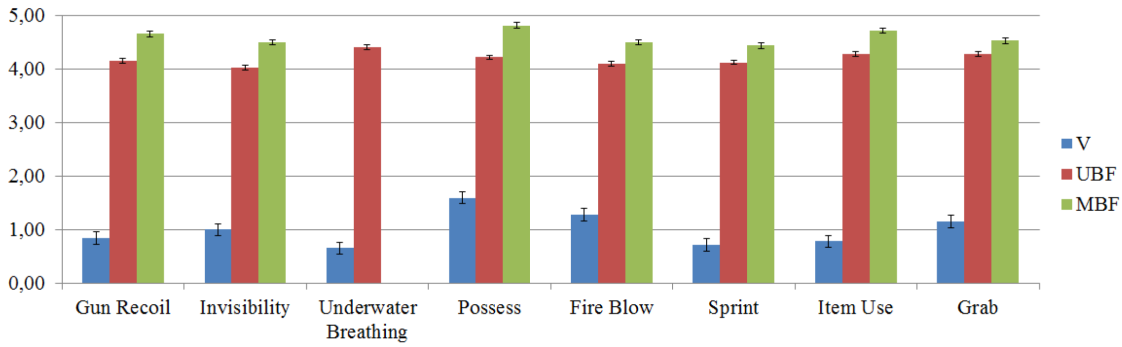

Figure 6.3: Mean Originality values between conditions with corresponding Standard Error measures.

Exhaustiveness was also expected to increase in the biofeedback conditions, although it seems some participants were able to cope with it during gameplay. It remains to be seen in future studies with longer testing periods whether the type of biofeedback used (unimodal or multimodal) or even biofeedback itself have an important influence on the players' willingness to play.

6.3 Questionnaire 2: Game Conditions

In the second questionnaire participants had to compare the three game conditions on their entirety instead of evaluating game mechanics individually. The questionnaire was filled after all three Prison Levels were completed to limit subjectivity - that is, by forcing players to compare all three gaming conditions at the same time, it forced them to reflect on each of them and weigh them against one another. The comparison of mean scores for each measured aspect is shown on Figures 6.4 and 6.5.

6.3.1 Originality, Preference, Playability

Originality was rated on a scale of 0 (No originality) to 5 (Very original) and Preference on a scale of 1 (Very low) to 5 (Very high). Players were also required to rate the sentence *"I feel that the game controls were an obstacle in my way to play well..."* [BC04] for each game condition using a seven-level Likert scale in order to quantify Playability (1 – completely disagree; 4 – neutral; 7 – completely agree). Mauchly's test statistic revealed that the sphericity assumption was met for Preference ($\chi^2(2) = 0.933, p > 0.01$) and Playability ($\chi^2(2) = 0.955, p > 0.01$) but not for Originality ($\chi^2(2) = 0.359, p < 0.01$). Therefore, Originality's degrees of freedom were corrected using a Greenhouse-Geisser estimate of sphericity ($\varepsilon = 0.60937$).

Statistical significance was encountered for all three parameters: Originality $F(2,62) = 107.82, p < 0.01$; Preference $F(2,62) = 24.905, p < 0.01$; Playability $F(2,62) = 23.188, p < 0.01$.

Tukey post-hoc tests revealed that:

Table 6.3: Q1 Originality - Statistical Analysis

	One-Way ANOVA		Tukey Post-Hoc		
Originality	F	p	V-UBF	V-MBF	UBF-MBF
Gun Recoil	203.19	< 0.001	< 0.001	< 0.001	0.046
Invisibility	183.73	< 0.001	< 0.001	< 0.001	0.054
Underwater Breathing	317.05	< 0.001		—	
Possession	127.76	< 0.001	< 0.001	< 0.001	0.020
Fire Blow	154.90	< 0.001	< 0.001	< 0.001	0.111
Sprint	236.54	< 0.001	< 0.001	< 0.001	0.234
Item Use	339.10	< 0.001	< 0.001	< 0.001	0.028
Grab	160.68	< 0.001	< 0.001	< 0.001	0.463

1. Players found both biofeedback versions more original than its vanilla counterpart ($p < 0.01$), with no difference detected between the unimodal and multimodal versions ($p > 0.01$). This result corroborates what was obtained in the first questionnaire regarding the various game mechanics.

2. Players preferred both biofeedback versions when compared to the vanilla version ($p < 0.01$). No significant difference was observed between the unimodal and multimodal versions ($p > 0.01$).

3. Players disagreed with the statement that game controls did not stop them from played well – in other words, it means that the playability of our game controls reached the desired level. However, Tukey tests indicated that as controls increased in complexity (vanilla being the least complex condition, followed by unimodal and then multimodal), players agreed less with the statement ($p < 0.01$).

6.4 IMI Post Experience Questionnaire

The IMI questionnaire that we used has seven parameters: Interest/Enjoyment, Perceived Competence, Effort/Importance, Pressure/Tension, Perceived Choice, Value/Usefulness and Relatedness. For the parameters: Interest/Enjoyment ($\chi^2(2) = 0.753, p > 0.01$); Perceived Competence ($\chi^2(2) = 0.958, p > 0.01$); Pressure/Tension ($\chi^2(2) = 0.737, p > 0.01$) and Relatedness ($\chi^2(2) = 0.805, p > 0.01$), Mauchly's sphericity assumption was met. For Effort/Importance ($\chi^2(2) = 0.533, p < 0.01$); Perceived Choice ($\chi^2(2) = 0.300, p < 0.01$) and Value/Usefulness ($\chi^2(2) = 0.633, p < 0.01$) it was violated. Therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.68157$, 0.58816 and 0.73176, respectively).

Statistical significance was encountered for: Interest/Enjoyment $F(2,62) = 58.903, p < 0.01$; Effort/Importance $F(2,62) = 40.743, p < 0.01$; Pressure/Tension $F(2,62) = 25.658, p < 0.01$; Perceived Choice $F(2,62) = 10.320, p < 0.01$; Value/Usefulness $F(2,62) = 92.141, p < 0.01$;

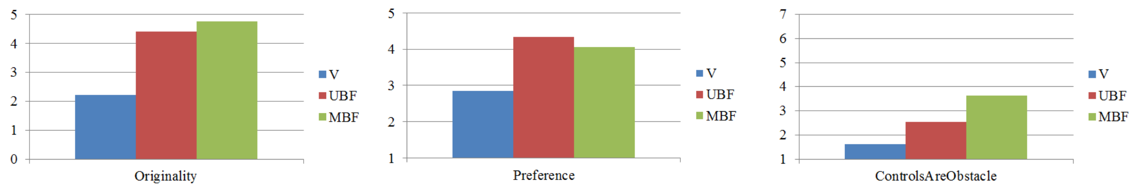

Figure 6.4: Mean Originality, Preference and Playability values between conditions.

and Relatedness $F(2,62) = 20.763, p < 0.01$ – but not for Perceived Competence $F(2,62) = 3.2746, p > 0.01$.

Tukey post-hoc tests revealed that players' Interest/Enjoyment, Effort/Importance, Pressure/Tension, Perceived Choice, Value/Usefulness and Relatedness were higher in both biofeedback conditions when compared to the vanilla version ($p < 0.01$), with no differences detected between unimodal and multimodal types ($p > 0.01$).

Regarding the Pressure/Tension parameter increase from the vanilla conditions to the biofeedback versions, we believe it is connected with the fact that they were experiencing a new form of interaction and felt the need to succeed in using the physiological devices. Although Perceived Competence registered a non-significant descending trend from the vanilla to the unimodal and multimodal conditions, we believe this trend is due to the players' large familiarity with the keyboard/mouse control. Given that this was their first experience with physiological control, we could expect similar levels of perceived competence if players' had the same level of familiarity across the three conditions.

We consider the increases from the vanilla to the biofeedback conditions on the Interest/Enjoyment, Effort/Importance, Perceived Choice and Relatedness parameters are related with Brown's "Engagement" type of immersion [BC04]. Players seemed to experience a rewarding sensation by observing their own physical actions reflected in the game and thus could relate more with the game – although on a small but statistically significant scale, players had more freedom on how to activate biofeedback mechanics rather than just pressing a button, as depicted in the Perceived Choice columns on Figure 6.5.

Players recognized the potential of this technology to enhance modern videogames using biofeedback technology, as shown in the Value/Usefulness parameter. Participant 21 had a very important view on adapting games to people with health issues or limited mobility:

- *"I think that these kinds of movements [biofeedback] are good for people with breathing issues or other limiting restrictions (...) it would be nice to blend the 3 modes for handicapped people." ("* (P21)

The IMI Post-Experience Questionnaire did not detect significant differences between the unimodal and multimodal types of interaction. However, we believe this is because the questionnaire was not designed to detect subtle differences – a limitation we acknowledged early on and strived to overcome through the remaining questionnaires and the Card Sorting process. While the two biofeedback versions do not have many differences in functionality, we believe that there are relevant differences to them in terms of the in-game context they should be used on (for a more in-depth discussion on this, see section 7.2).

Having presented the obtained results, in the following section we discuss their meaning as a whole towards the gameplay experience and further elaborate on the relevant differences between unimodal and multimodal biofeedback.

Table 6.4: Card Sorting Results - Describing Game Mechanics in Words (1)

	Sprint			Gun Recoil			Underwater Breathing		Invisibility		
	Vanilla	UBF	MBF	Vanilla	UBF	MBF	Vanilla	BF	Vanilla	UBF	MBF
Useless in-game	0%	3%	3%	0%	0%	3%	13%	0%	3%	3%	9%
Core in-game	28%	34%	44%	19%	16%	16%	9%	19%	19%	34%	31%
Simple	100%	78%	56%	84%	50%	6%	84%	50%	97%	47%	31%
Complex	0%	0%	3%	3%	16%	41%	0%	0%	0%	9%	34%
Realistic	6%	31%	63%	3%	69%	72%	9%	84%	0%	38%	38%
Imaginary	9%	9%	9%	0%	0%	0%	6%	6%	13%	34%	38%
Exhaustive	0%	9%	28%	6%	28%	41%	0%	22%	0%	16%	19%
Relaxed	41%	25%	16%	31%	13%	3%	22%	3%	31%	34%	19%
Confusing	0%	9%	3%	0%	9%	28%	0%	3%	0%	3%	6%
Intuitive	38%	50%	63%	53%	53%	44%	22%	97%	28%	41%	44%
Incomplete	22%	16%	9%	22%	34%	16%	25%	3%	16%	31%	3%
Complete	19%	22%	31%	22%	9%	28%	16%	66%	22%	25%	44%

Table 6.5: Card Sorting Results - Describing Game Mechanics in Words (2)

	Item Use			Possession			Grab			Fire Blow		
	Vanilla	UBF	MBF	Vanilla	UBF	MBF	Vanilla	UBF	MBF	Vanilla	UBF	MBF
Useless in-game	0%	0%	3%	0%	0%	0%	0%	0%	0%	19%	13%	13%
Core in-game	25%	31%	31%	25%	28%	38%	25%	34%	34%	13%	9%	9%
Simple	100%	75%	44%	94%	69%	34%	94%	56%	31%	88%	78%	34%
Complex	0%	0%	34%	0%	6%	25%	3%	6%	19%	0%	0%	28%
Realistic	3%	66%	81%	0%	13%	22%	3%	66%	69%	13%	78%	78%
Imaginary	3%	3%	6%	31%	53%	53%	16%	6%	6%	6%	3%	3%
Exhaustive	0%	3%	22%	0%	3%	6%	0%	6%	16%	0%	0%	31%
Relaxed	31%	41%	16%	19%	31%	25%	25%	34%	0%	31%	34%	19%
Confusing	0%	3%	13%	0%	3%	6%	0%	6%	25%	3%	0%	0%
Intuitive	41%	72%	50%	31%	34%	41%	34%	59%	59%	25%	91%	72%
Incomplete	31%	16%	3%	38%	16%	3%	19%	28%	38%	22%	13%	3%
Complete	16%	31%	47%	13%	22%	50%	19%	22%	34%	16%	31%	34%

Table 6.6: Q2 Originality, Preference and Playability between Conditions - Statistical Analysis

	One-Way ANOVA		Tukey Post-Hoc		
Conditions	*F*	*p*	V-UBF	V-MBF	UBF-MBF
Originality	107.820	< 0.001	< 0.001	< 0.001	0.166
Preference	24.905	< 0.001	< 0.001	< 0.001	0.432
Playability	23.188	< 0.001	0.009	< 0.001	0.001

Table 6.7: Q2 IMI Post Experience - Statistical Analysis

	One-Way ANOVA		Tukey Post-Hoc		
Conditions	*F*	*p*	V-UBF	V-MBF	UBF-MBF
Interest/Enjoyment	58.903	< 0.001	< 0.001	< 0.001	0.965
Perceived Competence	3.275	0.044	0.762	0.041	0.185
Effort/Importance	40.743	< 0.001	< 0.001	< 0.001	0.083
Pressure/Tension	25.658	< 0.001	< 0.001	< 0.001	0.947
Perceived Choice	10.320	< 0.001	< 0.001	0.001	0.951
Value/Usefulness	92.141	< 0.001	< 0.001	< 0.001	0.969
Relatedness	20.763	< 0.001	< 0.001	< 0.001	0.996

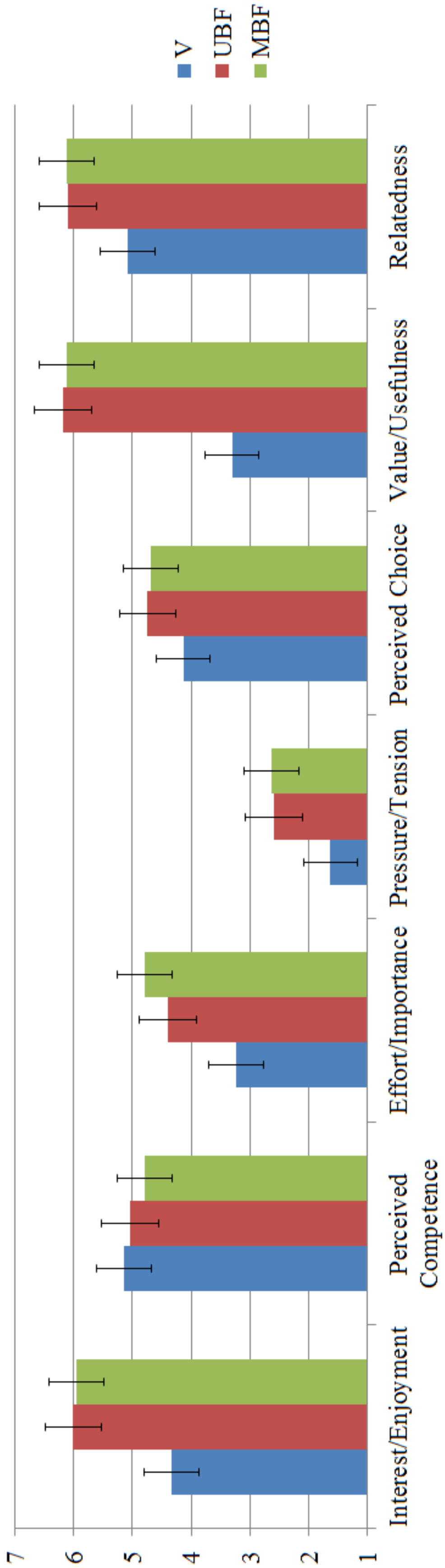

Figure 6.5: Mean IMI parameters between conditions with corresponding Standard Error measures.

Chapter 7

Results' Analysis and Discussion

We introduced a new variety of Direct Biofeedback in games that had not been explored before – Multimodal Direct Biofeedback – and theorize on the possible differences that it can bring for biofeedback games. We also analyse empirically our test game to provide a comprehensive case study on biofeedback games versus the current mouse/keyboard control schemes.

7.1 Fun Levels in Biofeedback Control

The Fun and Interest/Enjoyment metrics show strong evidence that players enjoyed playing the game more using biofeedback control than with a standard keyboard/mouse scheme. In our opinion, there are at least two factors that seem to contribute towards this outcome.

The first is the novelty factor of the technology: less than a handful of participants heard about biofeedback in videogames, and none of them ever had the chance to try and play videogames with it. The relative success of our implementation (and even previous works such as [NKLM11, DC07] can imprint an implicit biasing effect towards higher Fun ratings. The only way to assess whether the answer would be different – on a consumer-level setting such as a home use scenario – is to make a long term study involving several games (to mitigate game design issues and replicate accurately the life of the average gamer) with a biofeedback group and a control group. However, this study would require a sample population well over 100 subjects for each group and an extended time frame of over two weeks or even months. Unfortunately the number of existing biofeedback games is very little, which makes the idea infeasible and very hard to execute. The only way to truly assess the impact of biofeedback is to introduce it in a commercial context and see how gamers respond to it and adopt it (or not) over time.

One of our main concerns is that Direct Biofeedback videogames end up being more exhausting than today's videogames, due to their strong physical component. Some of our participants share this concern as well (as shown in Tables 6.4- 6.5) and this could negatively impact the average playtime of game sessions:

- *"I think it could become tiring on the long term and it wouldn't be so fun (in the situations where you play 10 hours per day)"* (P10)
- *"During the game it would be cool to switch between unimodal and multimodal according to the player's tiredness"* (P14)
- *"It's exhausting after a while..."* (P27)
- *"In this game it wouldn't be exhausting because you don't run for too long, but if it were mandatory it would be tiring"* (P30 on Biofeedback Sprint)

On the other hand, some cope well with it and even embrace it as a necessary consequence of this new gameplay style:

- *'It's tiring, but it's a* pleasant *tiring"* (P2 about both Biofeedback versions of Sprint)
- *"I also liked to contract the arm in order to activate Use and Grab – it was slightly uncomfortable but it was rewarding for the achieved realism' (...)'* (P5)
- *"In terms of precision pointing a gun and holding breath is more tiring, but to appreciate a game it becomes more interesting – however on a competitive level it's less useful"* (P8 on Gun Recoil)

The second factor that we feel it might impact the Fun ratings is related with the two Immersion theories described by Brown [BC04] and Ermi [EM07]. Brown's "Engagement" states that players need to invest time, effort and attention in order to reach that stage of immersion, once the game controls and the genre match the player's preferences; Ermi's "Challenge-based immersion" is *"the feeling of immersion when one is able to achieve a satisfying balance of challenges and abilities"* and *"can be related to motor skills or mental skills"* [EM07].

- *"In both biofeedback versions we have to imagine what we would normally do to activate the actions, it gives a little more of immersion and provides some differences in gameplay. It's also more challenging having to find out in these two what we have to do."* (P24)

The implicit effort that the biofeedback conditions demanded from players is a hint that players should feel more immersed in the biofeedback conditions, and Fun and Enjoyment are indicators that are related with the broad concept of Immersion.

One participant made an interesting remark in our game about immersion and biofeedback – we consider that biofeedback can be positively combined with other technologies to enhance further the sensation of immersion:

- *"In the biofeedback conditions I thought the interactivity was quite original [creative], both in the surrounding objects (the boxes and handles) as well in the actions that our character made like breathing or gun recoil control – they help providing the game a bigger feeling of immersion. The real feeling of immersion would be to account for head movement, like the Oculus Rift[1] device."* (P11)

Many users complained about the lack of an accelerometer (or a similar device to track spatial orientation) in our GLOVE device because they wanted to grab objects using only the glove:

- *"[in the biofeedback versions] you need to add an accelerometer on the glove"* (P5)
- *"The grab mechanic in both conditions does not work well because we have to use our hand closed (while grabbing the object) to move the mouse."* (P8)
- *"Grabbing the object and then returning to the mouse... it really makes me want to move it with the glove"* (P12)
- *"I don't like having to grab and then not being able to use the mouse"* (P21)

The mouse solution was not the best in terms of proper game design, but it was the only one in our reach in terms of available time and human resources. We hypothesize that Biofeedback can reach its full potential when combined with other technologies such as orientation trackers (e.g. accelerometer), virtual reality devices such as the Oculus Rift, or even with the existing motion-devices for games: the Microsoft Kinect, Nintendo Wii Remote or PlayStation Move.

7.2 Unimodal vs. Multimodal Game Design

Apart from Possess and Underwater, we were not able to uncover significant differences in Fun between unimodal and multimodal mechanisms. Players tended to use the "Realism", "Exhaustive" and "Complete" keywords to describe mechanics in the multimodal version – surprisingly, the unimodal Gun Recoil scored lower in "Complete" than the vanilla and multimodal versions. Game controls can be considered to be slightly harder to use on an increasing scale from vanilla to unimodal and multimodal – although some unimodal mechanisms can stand in par with the vanilla version (Gun Recoil, Fire Blow and Use) according to our statistical results.

Some players reached the consensus that the multimodal was the one with higher realism, but suffered from unnecessary levels of exhaustiveness. They valued the simplicity of the unimodal design, which was less also tiring:

- *"Having to contract the arm always to open doors is bad, it's better to do that only when firing the gun"* (P1 about the multimodal version of the Grab mechanic)

[1] http://www.oculusvr.com/ - "The Oculus Rift is a next-generation virtual reality headset designed for immersive gaming."

- *"In the unimodal version I also thought the experience was rewarding because it was quite interactive, simple and fits a gamer type that is more rookie and/or lazy – it still forces us to put effort but in a 'lighter' way... 'interactivity light'."* (P5)
- *"I think that the multimodal version tries to be more immersive, but it's too complex. The unimodal version can be immersive and simple. Both types bring added value when compared to the vanilla version."* (P10)
- *"It was confusing having to coordinate both things [the arm and breathing] (...) I think it wouldn't be the best combination and having to breath disturbs the action"* (P29 about Multimodal Gun Recoil)

Others valued the assertiveness and safety of the multimodal design, which added the highest realism, more sense of control or avoided sensor faults – either unintended activations of the sensors on their own (i.e. false positives) or the out-of-context activation of the players' abilities:

- *"I prefer the complexity of the multimodal version for having more details that make the game more realistic."* (P4)
- *"I think it makes sense having distinctions between the actions of diving and using a power [Invisibility] (...) the unimodal version wasn't very intuitive. (...) The multimodal version was more complete for distinguishing torch blowing and Possess"* (P10 – Invisibility and Underwater Breathing share the RESP sensor; Air Blow and Possess share the TEMP sensor)
- *"Closing the hand has more feedback for the game to know that it's what I want"* (P12 on Invisibility)
- *"I would choose the unimodal version only due to the detail of arm contraction in Use and Grab. Disregarding that I would use the multimodal version, since it uses ways that are more explicit and direct to indicate the actions that we want to perform – Possess, Invisibility, running with both legs, etc. (...) Breathing in and activating the Invisibility mechanism by accident doesn't seem good to me"* (P14)
- *"In the multimodal version when I used Possess, I felt more control by having to perform a gesture before activating the power than by having to blow on the enemies [in the multimodal version]. (...) In the unimodal version, having to breathe both to stay invisible and to breathe underwater was very distracting."* (P22)

Lastly, some participants reported that biofeedback broke game flow more often, most likely due to the time spent executing physical actions in comparison to pressing a button. Our "Playability" results in the second questionnaire seem to confirm this as well, but we think this is a by-product of exposing players to three different combinations of game controls in such a short time period. Additionally, players have years and years of familiarity with the keyboard/mouse control scheme.

- *"The multimodal version is a little too complex for a game where you have to be fast, with combat and action. The unimodal version has the better quantity of interaction when compared to the other two."* (P18)
- *"The biofeedback sections don't make the game hard in any way, but they make it less fluid in comparison with the vanilla version. While in the latter it's possible to walk and activate handles (Item Use) quite fast, when using biofeedback you need to stop and use the glove."* (P20)
- *"The multimodal version is more complex and breaks a little the pace of the game. The unimodal one allows us to play in a more fluid way."* (P26)
- *"In the multimodal version, while the actions were more realistic, tasks took longer to be executed. In the unimodal mode, actions had more realism than the vanilla version and the difference in time execution of actions was almost unnoticeable."* (P29)

Based on our players' feedback and our experience, we think that a mixed approach should be taken instead of a strict implementation of one of these biofeedback types. Long-term exhaustiveness, "naturalness" of the physical action and reliability of mechanism activation are the guidelines to be followed. As in modern games, books or movies, it depends on what feelings and sensations the game designer is trying to convey to the target audience.

For example, doors that open easily should not need overpowering arm contraction in order to open them: closing the hand and moving the arm without any contraction is more than enough. Objects that are light and heavy fall under this category as well. Putting out a matchstick or a candle should only need the TEMP sensor instead of breathing in all the air you can hold first. Considering the panoply of creative ways players can interact with a game, there may be scenarios where even simple actions should be difficult to execute. For example, consider a game section where the game character was shot in a gunfight and barricade him or herself until reinforcements arrive. However, being heavily injured, the character does not have much strength left to move the heavy objects needed to barricade the room. In this scenario it might be a good option to use multimodal biofeedback to purposely make this simple interaction more challenging and realistic, instead of resorting to, for example, quick-time events.

Common gameplay situations with harder obstacles (e.g. doors that will not budge) or more complex actions (e.g. manipulate or throw objects) can justify the use of Multimodal Biofeedback. The feeling of empowerment to activate a special power as in our game (Invisibility, Possess) is something that most participants felt it worked perfectly. This is another aspect where the potential of Multimodal Biofeedback is appreciated, which some of our participants dubbed as the "hand-sign system":

- *"Since I like Naruto it ends up being fun... "* (P3 about Multimodal Possession)
- *"I liked the part of making a gesture in Possess to control the enemies."* (P25)
- *"In the Possessing power I liked more the multimodal version because we needed to make hand signs in comparison with the unimodal version where you only had to blow air – the multimodal version was more realistic and interactive."* (P13)
- *"[except Sprint] In all other mechanisms, I prefer the multimodal version – I liked using a hand symbol combined with another action to activate the mechanisms."* (P5)

7.3 Possible Changes in Gameplay

The successful integration of Biofeedback gameplay mechanics in videogames will hardly follow a plug and play paradigm – not at least until a very mature, standardized period. As such, the design of biofeedback games is an important facet of their development. Thus, it is important to examine how our biofeedback game design choices impacted player experience. Following this thesis, Participant 19 provided the following differential analysis of Biofeedback and traditional videogames:

- *"The great difference between games that just use mouse and keyboard and those where sensors are used, for example, is that in games with sensors a higher importance is given to gameplay instead of more properly the game objective – for example in a shooter, by playing with mouse and keyboard the enemies are stronger and in bigger numbers, while when playing with sensors more importance is given to controls and movements of the player"* (P19)

Sensors can change the focus and gameplay of the game, which may require certain adaptations on the game logic to fit the use of the new devices. Some of the mechanics in Tables 6.4- 6.5 were considered slightly more relevant to gameplay ("Core in-game") in the biofeedback versions.

Regarding Perceived Choice differences in the IMI Questionnaire, Participant 22 said:

- *"[in biofeedback] Although it was something that was stored in the computer, I felt that the choices inside the game were mine"* (P22)

This was the only explicit statement regarding Perceived Choice recorded in the entire study. While participants weren't very expressive on this topic, the ANOVA tests showed that players experienced a slightly higher sense of Perceived Choice in the biofeedback conditions against the vanilla version of the game, where it was more neutral. It could be because some of the sensors could be activated in more than one way (e.g. EMG-Arm can be activated either by muscle contraction or by simply stretching the arm in any direction), while button-based actions typically are activated always the same way.

The fact that Participant 22 considered that the choices were her own could be because the fact that the game uses the player's own physiological signals to trigger actions inside the game could create a subconscious bond between the player's physical and virtual, in-game body. It stops being a matter of manipulating the character inside the game – which does what we tell him/her to do via keyboard/mouse commands – and becomes a situation where players can manifest their will by using their body actively to interact with the game world.

7.4 Limitations

Our investigation is limited in the sense that we built a game prototype on one genre from all of those that currently exist today (e.g. Racing games, Platformers, etc.). In order to assess the potential of Biofeedback, more prototypes need to be built in other game genres. Nacke et al. also refer this in their previous work and while our work builds on theirs', it is concerned with a vastly different game genre (2D Platformer vs. 3D First-Person Shooter with supernatural abilities).

Secondly, the appropriate hardware, robust frameworks and technology to process the data returned by the physiological devices for Biofeedback games are not yet available as of this time. Calibration of the physiological signals before gameplay was done manually. The fact that players would need to perform calibration manually and equip the biofeedback devices on their own – a process that took us approximately 15-20 minutes – makes Biofeedback infeasible for the everyday consumption of videogames at the current time.

Additionally, some of our participants experienced undesired activations in the TEMP and RESP sensors which we could not solve during the development phase. The TEMP sensor sometimes picked up very small activations that should be considered false positives. The RESP sensor did not have the expected variation due to a very small change in the chest volume while breathing. This mostly happened on participants with a more muscular chest area.

Everybody has a different physiology: this is an aspect that wasn't reported in other biofeedback games and should be carefully observed in future biofeedback prototypes.

Chapter 8

Future Work

Our initial exploration on this novel type of Direct Biofeedback opens several interesting research avenues for future projects. To the best of our knowledge, our prototype succeeded in combining, for the first time, more than one direct physiological sensor inside one game mechanic. It will be interesting to see how new prototypes build on our finding to further improve user experience and innovate on the design of biofeedback augmented gameplay mechanics. It would also be stimulating to see more theoretical studies on how level design guidelines should be adapted to accommodate for the idiosyncrasies that biofeedback introduces in the game design process. Lastly, it would be even more exciting to see these same studies applied to other game genres (e.g. Adventure, Exploration and Role Playing Games).

One particular detail we noticed is that one of our participants (P8) did not seem as pleased as the other participants regarding the biofeedback interaction. In his words, this type of interaction is not good for those who dedicate themselves to highly competitive game environments (e.g. online games like *"Starcraft II"*, *"Diablo III"* or *"League of Legends"*). This participant believed that this technology was ideal for those who like to appreciate the story or the 3D environment of a game. In our opinion, a study to compare the impact of biofeedback techniques on reported Fun between players with different playing philosophies would potentially yield valuable results. Players could, for example, be segmented as "narrative appreciator", "competitive", "social co-operator" or "environment fancier".[1]

We were unable to draw meaningful conclusions on whether contextual biofeedback mechanics (e.g. closing a hand has one effect if we are holding a door knob and another when grabbing an enemy by the neck) had any effect on the gameplay experience when compared with other types of biofeedback. In our unimodal prototype, some players affirmed they were confused when

[1] Author's note: at the time of the writing of this document we did not know about the existence of theories on personality and player types, and merely transcribed (literally) the player types suggested by P8. After recently taking knowledge of Bartle's "Hearts, Clubs, Diamonds, Spades" player model [Bar96], the four play styles described by Bartle (Killers, Achievers, Explorers, Socializers) show an interesting similarity to the concepts exposed by P8. In conclusion, Bartle's player model and related theories are a possible starting point to explore the connection between play styles and the effectiveness of Biofeedback.

using the RESP sensor to hold breath underwater and to activate invisibility outside of the water. TEMP was also used for Blow and Possession and some participants mentioned that it would be good to have a distinction in activation between the two mechanics. According to them, this was achieved in the multimodal version, albeit obviously with an increase in mechanic complexity as previously discussed. Exploring this challenge would be another interesting study from a game design perspective.

On a different note, we are unsure of the reaction players might show towards Biofeedback on a long-term period. The exhaustion factor should be accounted for when designing videogames, as it could become a severe obstacle to the longevity of a game. Even considering that our players spent a considerable amount of time playing the “GenericShooter 3000” in both its two biofeedback variants, it is impossible to predict how they are going to adapt. Furthermore, the side effects that repeatedly performing the same bodily actions may produce over extended time periods (years) still need to be thoroughly considered as improper usage may have ill-effects (e.g. carpal tunnel syndrome).

Finally, addressing some of the current limitations in games development for Biofeedback could benefit on-going research. Creating a high level, open-source framework capable of:

1. Eliminating undesired signal noise, and

2. Performing automatic sensor calibration

would lead to improved usability (less accidental activations) and a reduced dependency on specialized personnel. Addressing these issues would surely potentiate the use of this technology in the near future.

Chapter 9

Conclusions

We introduced the use of Multimodal Direct Biofeedback in videogames and compared it with standard mouse/keyboard control schemes, as well as with traditional Unimodal Direct Biofeedback (as introduced by Nacke [NKLM11]).

While the vanilla version of the game proved itself easier to use than the multimodal version in all mechanisms, not all of the unimodal mechanics were statistically more complex compared to the vanilla version. However, as most participants noted, higher complexity was generally not a negative aspect, as our results show that both biofeedback versions provide a more realistic feel when compared to the vanilla version. We also show that this feeling of heightened realism and depth is higher in the multimodal version – but at the expense of a more exhaustive gaming experience.

The IMI questionnaire also detected a significant contribution of biofeedback towards Fun in gameplay – most likely due to the satisfaction of players seeing their own body movements reflected inside the game. However, using only the IMI questionnaire renders us unable to evaluate the differences in functionality between the unimodal and multimodal types. To compensate for this, we attempted to further study the two biofeedback variants using the remaining questionnaires, the Card Sorting process and our participants' commentaries. These new metric were highly informative and allowed us to conclude that both biofeedback types have their place in the gameplay experience and should be combined simultaneously to add depth to videogames. The major guideline we were able to extract is that they should be combined according to the game's current context (e.g. lifting light objects versus heavy objects).

The recent developments in biofeedback interaction have left us sitting at an interesting crossroad in entertainment mediums: in books, movies and most current games, we assimilate the full gameplay experience while on a comfortable position from which we can abstract ourselves from. However, the latest motion-gaming (e.g. Nintendo Wiimote, PlayStation Move, Microsoft Kinect) are shifting towards more physically-active scenarios. The key to Direct Biofeedback's success could lie on the players' ability to "step out of the couch" – and our ability to motivate them to do so -, as they could be no longer “proxy-experiencing” the adventures of fictional characters, but rather living their own experiences on a fantasy world.

References

[Amb11] Mike Ambinder. Biofeedback in gameplay: How valve measures physiology to enhance gaming experience. In *Game Developers Conference*, 2011.

[Bar96] Richard Bartle. Hearts, clubs, diamonds, spades: Players who suit muds. *Journal of MUD research*, 1(1):19, 1996.

[BBM+07] Regina Bernhaupt, Andreas Boldt, Thomas Mirlacher, David Wilfinger, and Manfred Tscheligi. Using emotion in games: emotional flowers. In *Proceedings of the international conference on Advances in computer entertainment technology*, pages 41–48. ACM, 2007.

[BC04] Emily Brown and Paul Cairns. A grounded investigation of game immersion. In *CHI'04 extended abstracts on Human factors in computing systems*, pages 1297–1300. ACM, 2004.

[BEV+96] Edward B Blanchard, George Eisele, Alisa Vollmer, Annette Payne, Michael Gordon, Peter Cornish, and Linda Gilmore. Controlled evaluation of thermal biofeedback in treatment of elevated blood pressure in unmedicated mild hypertension. *Biofeedback and self-regulation*, 21(2):167–190, 1996.

[BLL02] Lars Bretzner, Ivan Laptev, and Tony Lindeberg. Hand gesture recognition using multi-scale colour features, hierarchical models and particle filtering. In *Automatic Face and Gesture Recognition, 2002. Proceedings. Fifth IEEE International Conference on*, pages 423–428. IEEE, 2002.

[BMA+01] Daniel Bersak, Gary McDarby, Ned Augenblick, Phil McDarby, Daragh McDonnell, Brian McDonald, and Rahul Karkun. Intelligent biofeedback using an immersive competitive environment. Paper at the Designing Ubiquitous Computing Games Workshop at UbiComp, 2001.

[Bro07] Jeremy J Brokaw. *Analysis of Game Interface Performance*. PhD thesis, WORCESTER POLYTECHNIC INSTITUTE, 2007.

[CGP07] Qing Chen, Nicolas D Georganas, and Emil M Petriu. Real-time vision-based hand gesture recognition using haar-like features. In *Instrumentation and Measurement Technology Conference Proceedings, 2007. IMTC 2007. IEEE*, pages 1–6. IEEE, 2007.

[CLK+02] Baek Hwan Cho, Jong-Min Lee, JH Ku, Dong Pyo Jang, JS Kim, In-Young Kim, Jang-Han Lee, and Sun I Kim. Attention enhancement system using virtual reality and eeg biofeedback. In *Virtual Reality, 2002. Proceedings. IEEE*, pages 156–163. IEEE, 2002.

[CPC+09] Marc Cavazza, David Pizzi, Fred Charles, Thurid Vogt, and Elisabeth André. Emotional input for character-based interactive storytelling. In *Proceedings of The 8th International Conference on Autonomous Agents and Multiagent Systems-Volume 1*, pages 313–320. International Foundation for Autonomous Agents and Multiagent Systems, 2009.

[DC07] Andrew Dekker and Erik Champion. Please biofeed the zombies: enhancing the gameplay and display of a horror game using biofeedback. *Proc. of DiGRA*, 2007.

[DLH+10] Qunxi Dong, Yongchang Li, Bin Hu, Qunying Liu, Xiaowei Li, and Li Liu. A solution on ubiquitous eeg-based biofeedback music therapy. In *Pervasive Computing and Applications (ICPCA), 2010 5th International Conference on*, pages 32–37. IEEE, 2010.

[EM07] Laura Ermi and Frans Mäyrä. Fundamental components of the gameplay experience: Analysing immersion. *Worlds in Play: International Perspectives on Digital Games Research. New York: Peter Lang Publishers*, pages 37–53, 2007.

[Ful08] Tracy Fullerton. *Game design workshop: a playcentric approach to creating innovative games*. Taylor & Francis US, 2008.

[GCC+10] Jeremy Gow, Paul Cairns, Simon Colton, Paul Miller, and Robin Baumgarten. Capturing player experience with post-game commentaries. In *Proc. 3rd Int. Conf. on Computer Games, Multimedia & Allied Technology (CGAT 2010)*. Citeseer, 2010.

[GDA05] Kiel Gilleade, Alan Dix, and Jen Allanson. Affective videogames and modes of affective gaming: assist me, challenge me, emote me. 2005.

[HB00] Sara Ilstedt Hjelm and Carolina Browall. Brainball–using brain activity for cool competition. In *Proceedings of NordiCHI*, pages 177–188, 2000.

[HGSW04] Andreas Haag, Silke Goronzy, Peter Schaich, and Jason Williams. Emotion recognition using bio-sensors: First steps towards an automatic system. In *Affective Dialogue Systems*, pages 36–48. Springer, 2004.

[HIO+05] He Huang, Todd Ingalls, Loren Olson, Kathleen Ganley, Thanassis Rikakis, and Jiping He. Interactive multimodal biofeedback for task-oriented neural rehabilitation. In *Engineering in Medicine and Biology Society, 2005. IEEE-EMBS 2005. 27th Annual International Conference of the*, pages 2547–2550. IEEE, 2005.

[IHVC09] Howell Istance, Aulikki Hyrskykari, Stephen Vickers, and Thiago Chaves. For your eyes only: Controlling 3d online games by eye-gaze. In *Human-Computer Interaction–INTERACT 2009*, pages 314–327. Springer, 2009.

[IM06] Poika Isokoski and Benoît Martin. Eye tracker input in first person shooter games. In *Proceedings of the 2nd Conference on Communication by Gaze Interaction: Communication by Gaze Interaction-COGAIN 2006: Gazing into the Future*, pages 78–81, 2006.

[KBWA04] Jonghwa Kim, Nikolaus Bee, Johannes Wagner, and Elisabeth André. Emote to win: Affective interactions with a computer game agent. *GI Jahrestagung*, 1:159–164, 2004.

[KEC+10] J Matias Kivikangas, Inger Ekman, Guillaume Chanel, Simo Järvelä, M Salminen, B Cowley, Pentti Henttonen, and Niklas Ravaja. Review on psychophysiological methods in game research. *Proc. of 1st Nordic DiGRA*, 2010.

[KLT+10] Kai Kuikkaniemi, Toni Laitinen, Marko Turpeinen, Timo Saari, Ilkka Kosunen, and Niklas Ravaja. The influence of implicit and explicit biofeedback in first-person shooter games. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 859–868. ACM, 2010.

[KT02] Manolya Kavakli and Jason R Thorne. A usability study of input devices on measuring user performance in computer games. In *Proceedings of First International Conference on Information Technology and Applications*, pages 291–295. Citeseer, 2002.

[LCCS07] Enrique Leon, Graham Clarke, Victor Callaghan, and Francisco Sepulveda. A user-independent real-time emotion recognition system for software agents in domestic environments. *Engineering applications of artificial intelligence*, 20(3):337–345, 2007.

[LG12] TJ Lavender and Diane Gromala. Audition, the game. *Procedia Computer Science*, 15:187–192, 2012.

[MA07] Regan L Mandryk and M Stella Atkins. A fuzzy physiological approach for continuously modeling emotion during interaction with play technologies. *International Journal of Human-Computer Studies*, 65(4):329–347, 2007.

[MB+91] MA Marcella Bryant et al. Biofeedback in the treatment of a selected dysphagic patient. *Dysphagia*, 6(3):140–144, 1991.

[MJNQ06] Liu Mingyu, Wang Jue, Yan Nan, and Yang Qin. Development of eeg biofeedback system based on virtual reality environment. In *Engineering in Medicine and Biology Society, 2005. IEEE-EMBS 2005. 27th Annual International Conference of the*, pages 5362–5364. IEEE, 2006.

[MRRE+11] Joe Marshall, Duncan Rowland, Stefan Rennick Egglestone, Steve Benford, Brendan Walker, and Derek McAuley. Breath control of amusement rides. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 73–82. ACM, 2011.

[NKLM11] Lennart Erik Nacke, Michael Kalyn, Calvin Lough, and Regan Lee Mandryk. Biofeedback game design: using direct and indirect physiological control to enhance game interaction. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 103–112. ACM, 2011.

[NL08] Lennart Nacke and Craig A Lindley. Flow and immersion in first-person shooters: measuring the player's gameplay experience. In *Proceedings of the 2008 Conference on Future Play: Research, Play, Share*, pages 81–88. ACM, 2008.

[Nog13] Pedro A Nogueira. Towards dynamically crafted affective experiences through emotional response player modelling. In *Ninth Artificial Intelligence and Interactive Digital Entertainment Conference*, 2013.

[NPI05] Arturo Nakasone, Helmut Prendinger, and Mitsuru Ishizuka. Emotion recognition from electromyography and skin conductance. In *Proc. of the 5th International Workshop on Biosignal Interpretation*, pages 219–222. Citeseer, 2005.

[NRON13a] Pedro A Nogueira, Rui Rodrigues, Eugénio Oliveira, and Lennart E Nacke. Guided emotional state regulation: Understanding and shaping players' affective experiences in digital games. In *Proceedings of the 9th Annual AAAI Conference on Artificial Intelligence and Interactive Digital Entertainment (AIIDE). Boston, Massachusetts, USA*, 2013.

[NRON13b] Pedro A Nogueira, Rui Rodrigues, Eugénio Oliveira, and Lennart E Nacke. A hybrid approach at emotional state detection: Merging theoretical models of emotion with data-driven statistical classifiers. In *Web Intelligence (WI) and Intelligent Agent Technologies (IAT), 2013 IEEE/WIC/ACM International Joint Conferences on*, volume 2, pages 253–260. IEEE, 2013.

[NRON13c] Pedro A Nogueira, Rui Rodrigues, Eugénio Oliveira, and Lennart E Nacke. A regression-based method for lightweight emotional state detection in interactive environments. In *Proceedings of the XVI Portuguese Conference on Artificial Intelligence (EPIA), Angra do Heroísmo, Açores, Portugal (to appear, 2013)*, 2013.

[NTR13] Pedro A Nogueira, Vasco Torres, and Rui Rodrigues. Automatic emotional reactions identification: A software tool for offline user experience research. In *Entertainment Computing–ICEC 2013*, pages 164–167. Springer, 2013.

[PCH+11] Matthew KXJ Pan, Jih-Shiang Chang, Gokhan H Himmetoglu, AJung Moon, Thomas W Hazelton, Karon E MacLean, and Elizabeth A Croft. Now where was i?: physiologically-triggered bookmarking. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 363–372. ACM, 2011.

[PSGO13] Avinash Parnandi, Youngpyo Son, and Ricardo Gutierrez-Osuna. A control-theoretic approach to adaptive physiological games. In *Affective Computing and Intelligent Interaction (ACII), 2013 Humaine Association Conference on*, pages 7–12. IEEE, 2013.

[RBF+08] Laura Rocchi, Marco Benocci, Elisabetta Farella, Luca Benini, and Lorenzo Chiari. Validation of a wireless portable biofeedback system for balance control: preliminary results. In *Pervasive Computing Technologies for Healthcare, 2008. PervasiveHealth 2008. Second International Conference on*, pages 254–257. IEEE, 2008.

[RGP+10] Giuseppe Riva, Andrea Gaggioli, Federica Pallavicini, Davide Algeri, Alessandra Gorini, and Claudia Repetto. Ubiquitous health for the treatment of generalized anxiety disorders. 2010.

[RSL05] Pramila Rani, Nilanjan Sarkar, and Changchun Liu. Maintaining optimal challenge in computer games through real-time physiological feedback. In *Proceedings of the 11th International Conference on Human Computer Interaction*, pages 184–192, 2005.

[SBC+11] Cara E Stepp, Deanna Britton, Chelsey Chang, Albert L Merati, and Yoky Matsuoka. Feasibility of game-based electromyographic biofeedback for dysphagia rehabilitation. In *Neural Engineering (NER), 2011 5th International IEEE/EMBS Conference on*, pages 233–236. IEEE, 2011.

[SG06] J David Smith and TC Graham. Use of eye movements for video game control. In *Proceedings of the 2006 ACM SIGCHI international conference on Advances in computer entertainment technology*, page 20. ACM, 2006.

[SLR+11] Evan A Suma, Belinda Lange, Albert Rizzo, David M Krum, and Mark Bolas. Faast: The flexible action and articulated skeleton toolkit. In *Virtual Reality Conference (VR), 2011 IEEE*, pages 247–248. IEEE, 2011.

[TNS13] Luís Filipe Teófilo, Pedro Alves Nogueira, and Pedro Brandão Silva. Gemini: A generic multi-modal natural interface framework for videogames. In *Advances in Information Systems and Technologies*, pages 873–884. Springer, 2013.

[Tor13] Vasco Pereira Torres. Development of biofeedback mechanisms in a procedural environment using biometric sensors. Master's thesis, 2013.

[WSN10] Qiang Wang, Olga Sourina, and Minh Khoa Nguyen. Eeg-based "serious" games design for medical applications. In *Cyberworlds (CW), 2010 International Conference on*, pages 270–276. IEEE, 2010.

[YMJ10] Georgios N Yannakakis, Héctor P Martínez, and Arnav Jhala. Towards affective camera control in games. *User Modeling and User-Adapted Interaction*, 20(4):313–340, 2010.

REFERENCES

Appendix A

Card Sorting - Plotted Charts

For ease of interpretation of the data presented on Tables 6.4- 6.5, we plotted the results of the card sorting process. The results are grouped in the same manner they are presented on Tables 6.4- 6.5:

- Useless in-game / Core in-game;
- Incomplete / Complete;
- Imaginary / Realistic;
- Relaxed / Exhausting;
- Simple / Complex;
- Confusing / Intuitive.

Notice, however, that the presented comparison pairs are merely one way to interpret the collected data. Other pairs could be established to extract useful information - for example: “Complex vs. Confusing”, “Simple vs. Intuitive” or “Realistic vs. Exhausting”.

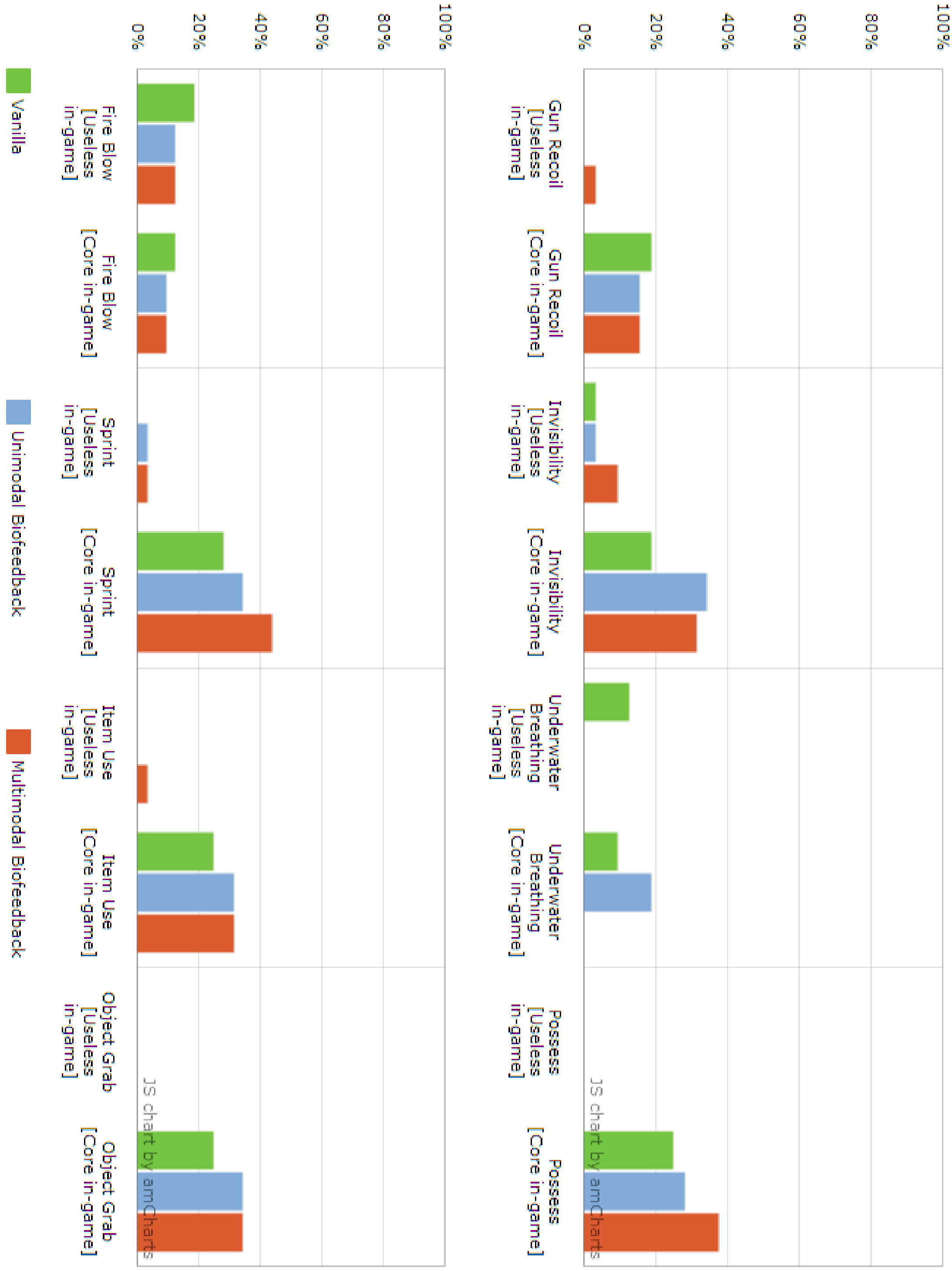

Figure A.1: Useless in-game vs. Core in-game.

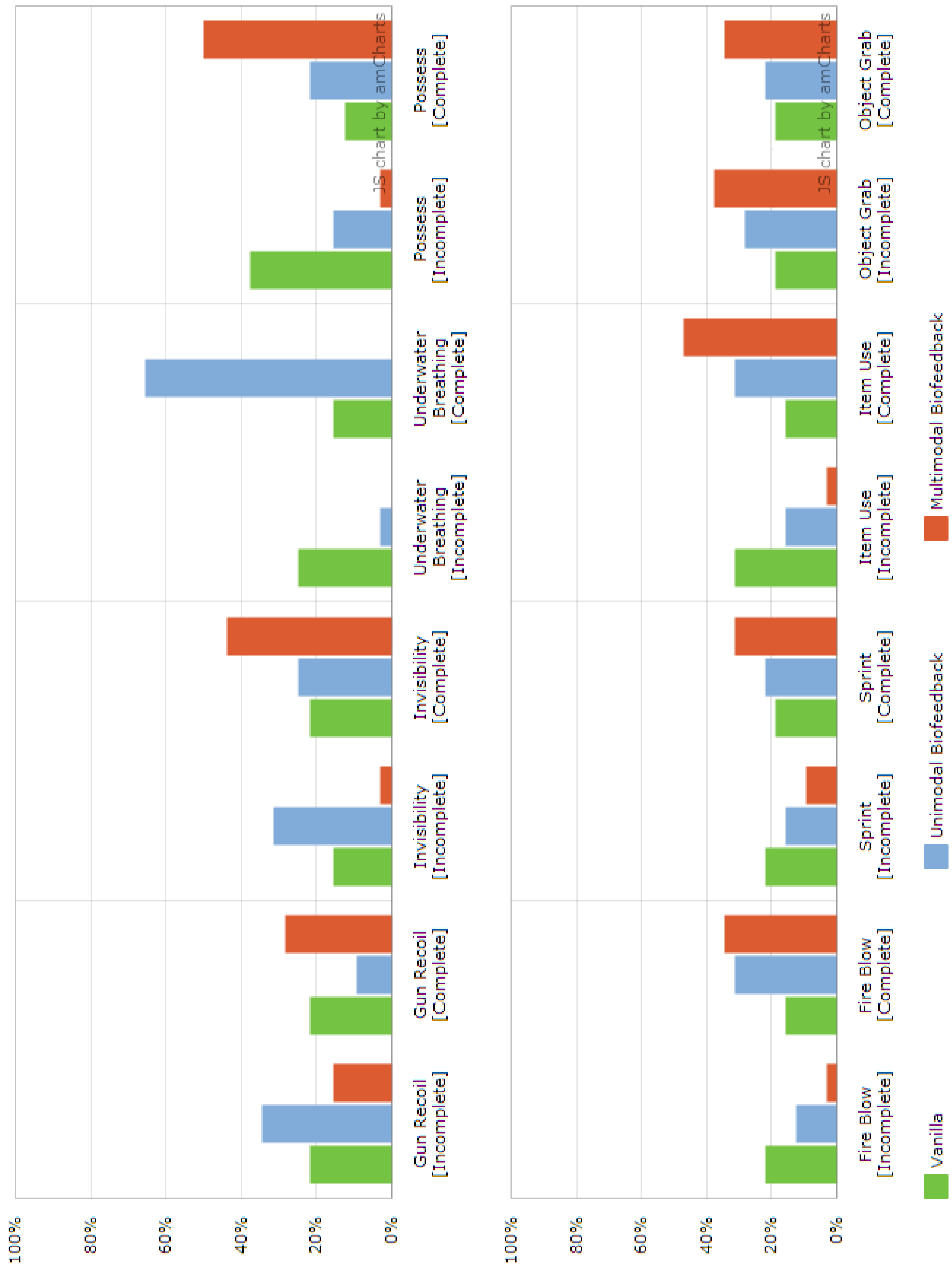

Figure A.2: Incomplete vs. Complete.

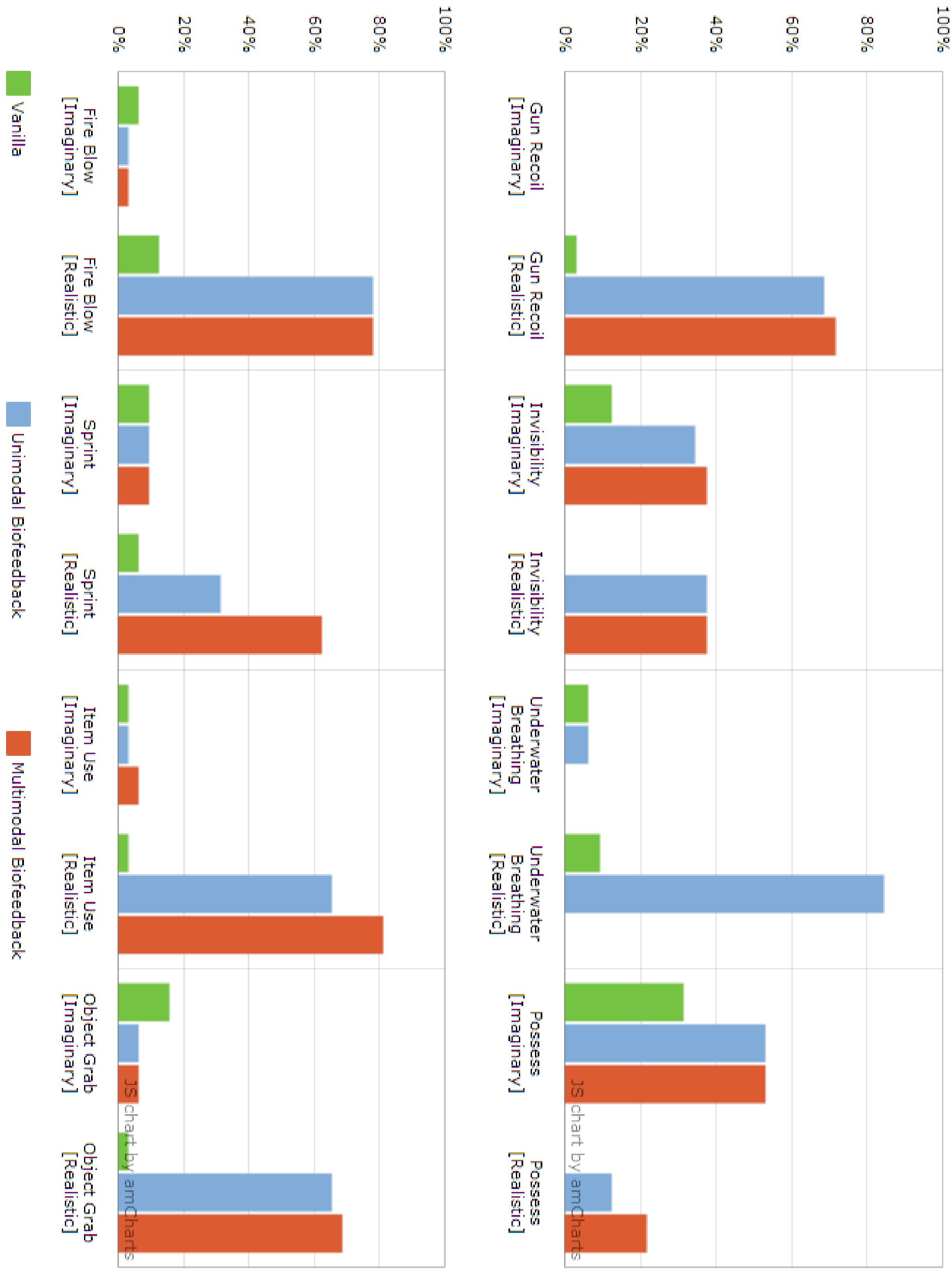

Figure A.3: Imaginary vs. Realistic.

Figure A.4: Relaxed vs. Exhausting.

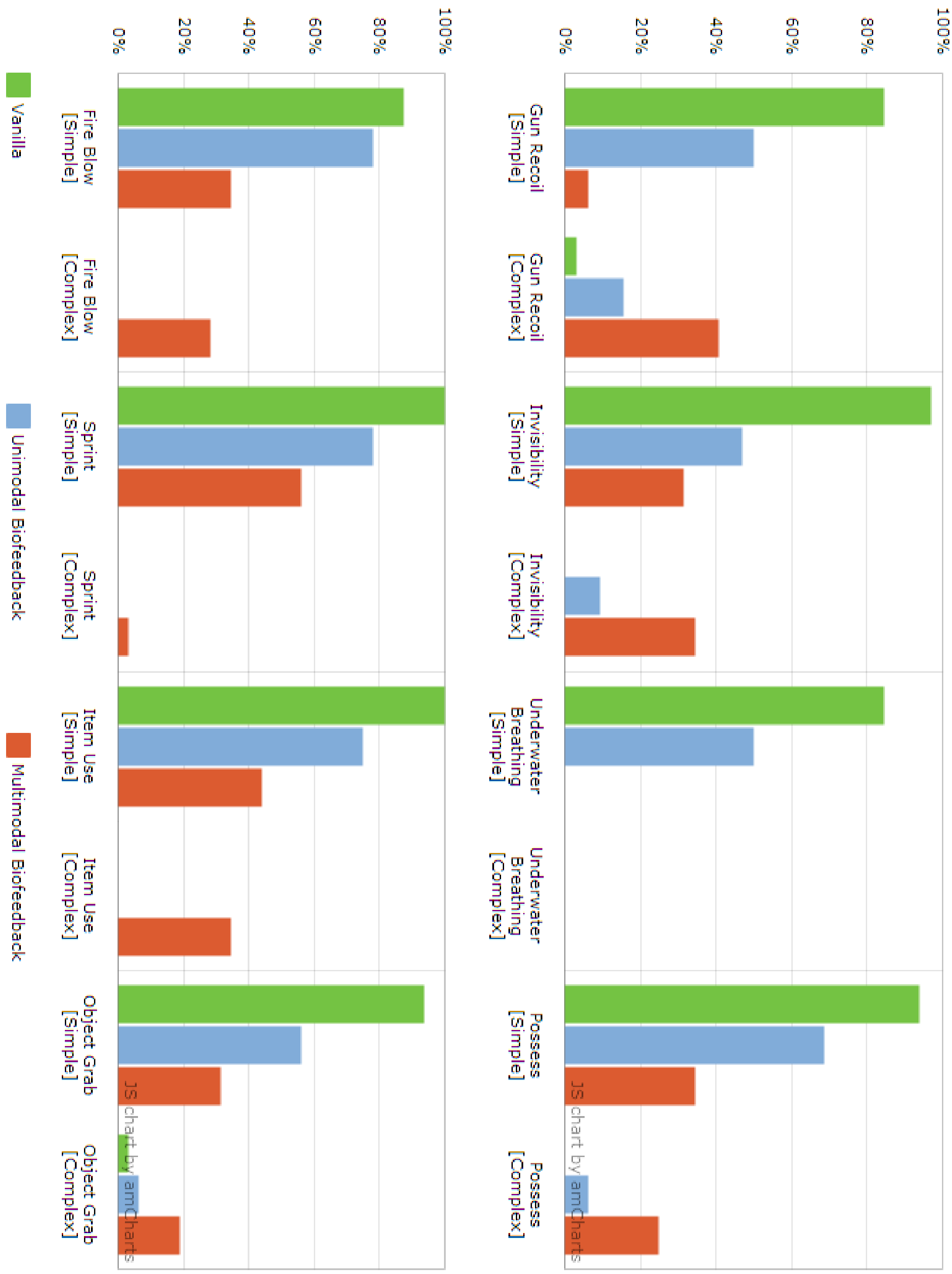

Figure A.5: Simple vs. Complex.

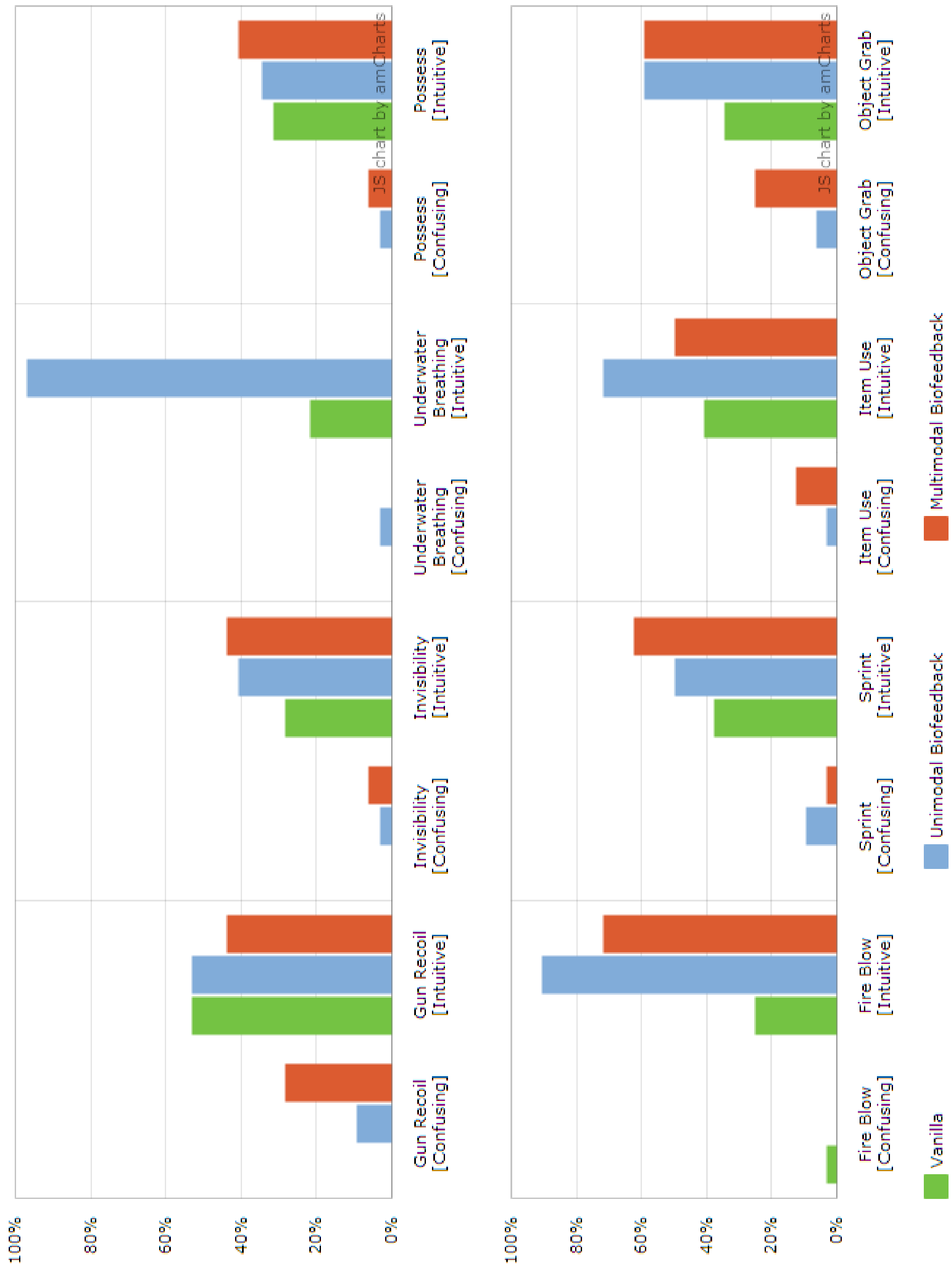

Figure A.6: Confusing vs. Intuitive.